The Evolving Urban Community and Military Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities

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14. ABSTRACT
Urban growth is directly associated with several of the challenges: threatened/endangered species, airborne noise, air quality, and radio frequency interference. This effort addressed three key installation needs:
1. Identification of installations most at risk to encroachment using nationally available data sets.
2. Prediction of future urban-growth encroachment challenges based on proposed regional plans.
3. Projections of the loss of military training and testing opportunities.

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List of Acronyms

APA	American Planning Association
AICUZ	Air Installation Compatible Use Zones
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BRAC	Base Realignment and Closure
BLS	Bureau of Labor Statistics
CERL	Construction Engineering Research Laboratory
CHPPM	US Army Center for Health Promotion and Preventive Medicine
CHSSI	Common High-performance Software Support Initiative
CRREL	Cold Regions Research and Engineering Laboratory
CONUS	CONtinental US
DEM	Digital Elevation Model
DoD	Department of Defense
ERDC	Engineer Research and Development Center
fbLEAM	Fort Benning LEAM
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EROS	Earth Resources Observation System
ESRI	Environmental Systems Research Institute
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FDM	Fugitive Dust Model
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FRAGGLE	Fragmentation Analysis Model
FWS	Fish and Wildlife Service
GIS	Geographic Information System
HHS	Health and Human Services
HSPF	Hydrologic Simulation Program in FORTRAN
gLEAM	Gateway (St Louis) LEAM
GRASS	Geographic Resources Analysis Support System
HPCMO	High Performance Computer Modernization Office
IRRIS	Intelligent Road/Rail Information System
JAWRA	Journal of the American Water Resource Association
JLUS	Joint Land Use Study
LEAM	Land use Evolution and impact Assessment Model
LEAMecon	LEAM's economic impact model
LEAMluc	LEAM's land use change model
LEAMram	LEAM's residential attractiveness model
LEAMtom	LEAM's training opportunities model
LEAMtran	LEAM's transportation model
LEAMwq	LEAM's water quality model
mLEAM	Military version of LEAM

MSRC	Major Shared Resource Center
NACJD	National Archive of Criminal Justice Data
NASA	National Aeronautics and Space Administration
NERC	North American Electric Reliability Council
NERL	National Exposure Research Laboratory
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NWS	National Weather Service
OEA	Office of Economic Adjustment
OSD	Office of the Secretary of Defense
PNNL	Pacific Northwest National Laboratory
SDSS	Spatially-explicit Dynamic Simulation System
SERDP	Strategic Environmental Research and Development Program
SIRRA	Sustainable Installation Regional Resource Analysis
SME	Spatial Modeling Environment
SROC	Senior Readiness Oversight Council
SSA	Strategic Sustainability Assessment
SSA	Sustainable Sandhills Analysis
SRWG	Sustainable Ranges Working Group
TABS	Total Army Basing Study
TTAWG	Technology Thrust Area Working Group
USCB	United States Census Bureau
USGS	United States Geographical Survey

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Project Managers

Brian Deal, University of Illinois, Department of Urban and Regional Planning
Originally with ERDC-CERL, Brian put together the original proposal for the project based on his then current PhD project work. Completing his PhD under this project, he took a position at the University of Illinois, created the LEAMlab within his department, and continued to guide the project.

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Directed and guided the SIRRA research, development, and application effort. She has

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Alan Anderson, ERDC-CERL
: Coordinated the work of Dr. George Gertner to help calibrate the LEAM land use change model.

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Funded LEAM research and development and its application for forecasting urban patterns around Peoria, East St. Louis, and Chicago.

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With Illinois, funded LEAM applications for the St. Louis greater metropolitan area.

Fort Knox

Funded an mLEAM analysis of its surrounding areas.

1 Executive Summary

On June 20, 2000, the Senior Readiness Oversight Council (SROC) convened to review the challenges to military readiness resulting from the "encroachment" of military training and testing lands by various sources and means. The Council concluded that indeed the military continues to lose valuable resources and that a coordinated approach be developed to deal with the challenge. On November 27th the SROC approved a plan that included the establishment of a Sustainable Ranges Working Group (SRWG) with Service and OSD membership. The SROC identified the following as the top encroachment issues:

Urban growth	Airborne noise
Threatened/Endangered Species	Air quality
UXO/Munitions Constituents	Frequency
Marine Mammal Protection	Outreach

Urban growth is directly associated with several of the challenges: threatened/endangered species, airborne noise, air quality, and radio frequency interference. SERDP responded with a statement of need (SON) seeking R&D to help identify and alleviate these SROC identified challenges to current and future military readiness. We proposed an effort to address two key installation needs:

1. Identification of installations most at risk to encroachment using nationally available data sets.
2. Prediction of future urban-growth encroachment challenges based on proposed regional plans.

Overview of SIRRA

No comprehensive and unbiased capability existed that could allow Services and DoD to identify which installations had the greatest encroachment challenges. Under this project we developed a methodology and a product that met this challenge and has been used extensively by installations, Service headquarters, and OSD. SIRRA is the Sustainable Installation Regional Resource Analysis system and is publicly available through the Internet. It uses several dozen national databases, grouped into ten issue areas, which can be queried by installation, service, or region of the country. Installations can be rank-ordered based on the severity of one or more sustainability factors. SIRRA has been presented at numerous conferences, has been used in the BRAC05 process, by the TABS (Total Army Basing Study) office, and by many installations and DoD offices.

Overview of LEAM

LEAM is short for "Land use Evolution and Impact Assessment Modeling". It is a synthesis of approach and software that allows a regional planning stakeholder community to explore the long-term (20-40) year consequences of proposed regional plans. The LEAM approach has been successfully applied to regions containing Peoria, Illinois; East St. Louis and St. Louis, Missouri; Traverse City, Michigan; and now the Chicago Metropolitan Area extending across Wisconsin, Illinois, and Indiana. It has also been tested with the Fort Benning and Scott Air Force Base communities. Generally speaking, the LEAM approach proceeds as follows:

1. A quick generation of urban growth is completed using nationally available data.

2. Results are presented at a regional planning charrette which then poses the following questions to participants:
   - What is right and what is wrong with the projections?
   - What local data and information is available to replace the national data?
   - What are the perceived encroachment problems/challenges?
   - What are the local drivers to growth?
   - What regional planning ideas should be tested?
3. The LEAM urban growth model is modified, including changes to the source code, to capture the needs identified in the charrette. A 9 or 20 sector economic model is used to project future economic and population growth based on proposed major changes in employment (e.g. installation mission changes).
4. The model is calibrated – often with historic census data
5. Revised model outputs are reviewed by the stakeholder community until they are satisfied with the base model projections.
6. Regional planning proposals are tested with the model
7. As needed/requested, future urban patterns are input into various models such as:
   - Transportation models
   - Habitat fragmentation models
   - Economic impact models
   - Utility (e.g. water, electric grid, and sewer) models
8. Results are captured in a report for general public consumption and presented at regional stakeholder meetings
9. The new localized LEAM model often becomes part of the regular tools of the community to test further regional planning suggestions.

Each full application of LEAM results in an urban growth model specially created to address the specific needs of the target communities. Step 1, above, is accomplished with a generic version of LEAM's land use change model. This software is written in the "C" language and, like RSim, owes its beginnings to the SLEUTH model. It is 30-meter grid-cell based, uses a 1-year time step, and generates future urban patterns across a region based on calculated dynamic attractiveness of undeveloped areas to new urban residential, commercial, and open-space. Raw GIS maps are processed with in-house ESRI GIS scripts to create the needed input files for the LEAM land use change model. Results of the model are further processed with ESRI-GIS for reporting and image production purposes.

LEAM applications are tailored to meet the specific needs of target communities and rely heavily on intensive interactions with multiple stakeholders across a region.

Overview of mLEAM

While LEAM provides a powerful approach designed to specifically address the regional planning challenges facing a community composed of many stakeholders, mLEAM provides a very inexpensive and quick, though generic, approach to project residential growth around military installations and forecast the implication of that growth on future military training and testing opportunities. mLEAM analyses begin with a GIS technician downloading free and nationally available data such as land cover (NLCD), elevation (DEM), roads/highways, and state/federal lands. These are processed to generate raster and vector maps in a common UTM projection and common area extending through a defined set of counties. These maps are then

loaded with scripts into the Linux/Unix based GRASS GIS and automatically processed. There are three primary steps.

1. LEAMram is the residential attractiveness model that generates a residential attractiveness map based on the combined attractiveness of each 30-meter square area with respect to distances to roads, highways, interstates, intersections, employment, other residential, trees, and water. The attractiveness is measured through an analysis of the current pattern of residential areas across the study area.
2. LEAMluc is a version of the LEAM land use change model. Only residential development is generated however because the primary incompatible land use challenge involves military activities and residential.
3. LEAMtom is the training opportunities module, which runs a number of new GIS analyses that predicts the probability of complaints from residential neighbors in response to military generated noise, dust, and smoke. Night sky illumination due to city lights is also synthesized.

Each of these steps generates results not only within the GRASS GIS, but automatically to a web site for immediate end-user viewing. Posted results include text, map images, urban growth movies, and GIS maps for downloading into a user's local GIS software.

2 Objective

As described in the original proposal, the main objective was the evaluation of the threat of urbanization on military installations and missions. This was accomplished through the development of an analytical and visually based dynamic spatially explicit decision support system (SDSS) to improve the decision-making processes and land management practices of the military and adjacent private sector communities and move them toward more compatible and sustainable outcomes.

This project developed a suite of products that help 1) identify the current encroachment challenges associated at military installations and 2) project future challenges based on current and proposed regional plans and population/economic projections. The Construction Engineering Research Laboratory (CERL) partnered with the University of Illinois to expand work originally funded by the National Science Foundation (NSF) on the Land use Evolution and Assessment Modeling (LEAM) system. The LEAM environment was further developed to test proposed regional plans with respect to the direct and indirect impacts on an installation's ability to support current and future training and testing. LEAM is able to help predict, through scenario-based planning techniques, where and when military and private sector planning initiatives may be in conflict.

Specific overall objectives within this framework include:

1. Identification of military installations most at-risk from the urbanization and encroachment of adjacent land uses by identifying exogenous installation variables.
2. Development of a spatially explicit dynamic simulation system (SDSS) (LEAM) that allows prediction of future residential development around military installations in response to proposed regional plans.
3. Predicting training/testing land suitability on and off-installations with respect to predicted urban patterns. This includes:
    a. Prediction of community tolerance of training/testing noise, dust/smoke, and radio frequency interference.
    b. Prediction of night-training suitability around military lands.
4. Application of the model and assessment methodology to selected at-risk DoD installations.

All of these criteria reflect the overall goals: to improve the gaps in our basic understanding of the risks to military operations and training lands associated with land use transformation outside the military installation boundary; and to improve the overall sustainability of military installations through the application of data and predictive models for urban change and environmental impact assessments. Once the fundamental knowledge gaps have been filled, the application of the SDSS, LEAM, to identified at-risk installations can easily be done.

3 Background

Military installations comprise a large and long-term investment made by the American people for of national defense. They embody enormous capital costs in infrastructure and personnel that are critical for sustaining military readiness and power projection capabilities. But the constant and fast paced urban growth of once rural land uses adjacent to our military assets is now threatening to compromise the integrity of this investment by undermining the military's ability to maintain its mission focus. Land use transformation near military installations affects how military lands are managed. Loss of habitat 'outside the fence-line' can increase the importance of threatened and endangered species habitat inside the installation boundary. Growth of surrounding communities can also help decrease the regional economic importance of the installation, advancing interest in converting military installation lands toward more lucrative private sector purposes. Planners for the installations and the surrounding communities must separately and jointly make decisions that effectively deal with this long-term threat. It is critical that they understand and agree on the key factors that determine and impact the region's overall sustainability. The capabilities developed through the project will help elucidate where the threat of urban growth may negatively impact the military mission.

Obtaining clearer understanding of the dynamic and spatial interactions between the military community's mission and land use needs, and the adjacent community's goals, planning policies and probable spatial growth patterns is an important step toward resolving some of these issues. By predicting the urban transformations near military installations future conflicts can be illuminated for military land use and resource managers. For example:

When will military installation land become more valuable as private sector land?

How will changes in the regional distribution of threatened and endangered species habitat affect the operation of military installations?

What are the strategic land ownership and land use changes that can improve the military's ability to train in the future.

Future weapon systems will require more space for training. How can we affect land use patterns now to allow for the future training needs?

What agreements with local communities (county or state governments) will ensure the maintenance of threatened habitat and the opportunity for urban growth without impacting the military mission?

This project developed a land use transformation modeling environment to address these questions at identified and selected at-risk installations.

3.1 Identifying At-Risk Installations

When the exogenous effects of community growth are a significant source of risk to military land uses, installations must evaluate what is happening "outside the fence line." Identifying key measures that could indicate when an installation becomes at risk, and monitoring for those changes in the surrounding areas, would create a proactive environment to protect critical existing assets. The primary goal of this work was to identify and evaluate nationally scaled indicators of risks to military lands due to exogenous effects of local area growth. Information

derived from this can help determine which DoD sites are most at-risk and in need of more detailed modeling and analysis.

This work builds upon previous efforts conducted by the Construction Engineering Research Laboratory (CERL) and the University of Illinois Geographic Modeling Systems (GMS) Lab (Deal, 2001; Goran, 2000). The previous work was a cursory examination of a limited set of demographic factors. This new work included additional demographics, economic data and urbanization measures, and allows comparison of results of including or excluding different factors.

All DoD installations within the continental Unites Sates (CONUS) were considered, and the derivation of a set of current DoD land holdings in a spatially referenced format. A preliminary set of risk measures including population (US Bureau of the Census), earnings (US Department of Commerce), land use change patterns (USGS), employment (US Bureau of Labor Statistics) and urban development in statistical areas (US Department of Agriculture and US Bureau of the Census) were considered (all factors have a spatial reference).

The study explored development of risk indicators at three scales: summary, county of residence, and area of influence. The summary level looked at aggregate data to develop descriptive characterization of installation properties nationwide. This level evaluated properties by state, and served as a useful scale for developing the ranking and assessment approach. The county of residence level required associating each installation property with a home county, establishing a better association for the assessment of neighboring population, economic, and land use relationships. This level also includes some non-county local area factors such as urban areas proximity. The third level, local area of influence, is more expansive than county of residence because it considers all neighboring counties and additional time-series analyses for each installation. Because of the additional complexity, this level is an illustration limited to one property. It provides a useful comparison on how choice of scale effects the assessment of risk and the importance of detailed review.

Data from USGS Landsat 7 with a 30 meter spatial resolution and NASA's EOS satellite with 15 meter spatial resolution was also considered to identify and monitor the influence of surrounding community growth patterns on selected military installation boundaries and training lands. These remote sensing devices along with National Aerial Photography data were used to compare temporal land use transformations (Acevedo, 1997). The USGS EROS Data Center (USGS-EDC) organized and analyzed remote sensing data.

3.2 Spatial Simulation Modeling for Urban Growth

Extensive literature exists in the urban planning and regional science fields relating to large-scale urban models. Historically, computer based simulations of urban problems appears to have its origin in the 1950's metropolitan transportation studies (Klosterman, 1994) and the geographic accessibility models that resulted. Theoretical urban simulation models for locating residential development and retail centers were then added to the to previously simple and straightforward transportation models in the 1960's. These successes encouraged a number of ambitious, expensive and highly visible attempts to build large-scale metropolitan simulation models. In 1973 Douglas Lee wrote a cornerstone article in the Journal of the American Planning Association that effectively eliminated large-scale urban modeling research for nearly 20 years.

The article titled - A Requiem for Large-Scale Models, depreciated the then ambitious attempts to develop large-scale computer models of the metropolis (Lee, 1973).

Despite the practical failures of the large-scale modeling efforts, the mathematical programming techniques developed for use in these models were found to be useful for constrained and well structured problems with a specified number of calculable variables, well-defined goals, and firmly established technical solutions. In 1969 Jay W. Forrester wrote his seminal work –Urban Dynamics (Forrester, 1970), in which he develops a computer based dynamic simulation tool (a precursor to current dynamic modeling software) to describe the changing fabric of the urban environment. Forrester's modeling tool was focused on a somewhat constrained problem set, but it enabled planners to introduce a temporal approach into previously static methodologies. More recent applications have used a mathematical ecology approach. Mathematical models of the urban dynamic constructed by Allen (1978) and Wilson (1981) are believed to be among the first attempts to adapt a non-linear ecological approach. In terms of explicit urban ecological modeling, Dendrinos (1979) takes the concept one step further, addressing dynamic non-linear interdependencies, stability and equilibrium, conditions that they argue are necessary components of urban systems modeling. These mathematical models of the urban dynamic are useful for the development of a visually based land use transformation model.

Recent work in urban systems modeling has begun to utilize an arithmetic computational approach to integrate socioeconomic and geographically based information into a dynamic and spatially oriented visualization tools (Batty, 1992; Birkin, 1990; Clarke, 1997; Deal, 2001; Deal, 2001; White, 1997). Graphic, dynamic spatial modeling techniques are also currently being used to analyze large and complex, ecologically based systems (Deal, 2000; Hannon, 1994; Hannon, 1997; Westervelt, 1997; Westervelt, 1995). These tools provide information that is clearer, more accurate, and graphically illustrative than conventional linear modeling systems. The application of these techniques can help improve our fundamental understanding and communication of the dynamics of land use transformation and the complex interactions between urban change, military installations and sustainable systems. These tools are utilized in the development of the mLEAM modeling system.

The University of California at Berkeley conducted a study for the California Technology, Trade, and Commerce Agency to assess key California military installations threatened by urban growth (Landis, Reilly et al. 2001). This study considered the magnitude of potential urban encroachment on 23 of the major installations in the state and then conducted a more detailed study of four installations facing significant urban growth pressures. The study concluded that encroachment is not a systemic problem, but rather important at a only a few installations, and with adequate advance planning, conflicts "should remain manageable."

Many urban growth simulation models have been developed by a variety of different organizations for purposes ranging from research, education, city planning and regional planning (EPA 2000). Each captures a different combination of the factors involved in growth in order to answer certain questions. Models can be separated into two distinct spatial scales: city and region. Models such as DRAM/EMPAL and MEPLAN are popular in the US and overseas, respectively, and focus on identifying growth by income and housing costs. These, and other models are focused on the city itself and deal with growth over the course of a couple of decades.

Regional models are more concerned with addressing questions regarding gross growth patterns over many decades and the associated implications with respect to environmental measures. Military installation encroachment questions are asked at this scale and include:

- Where are people likely to be living in the next 50 years?
- What percent of important habitat in the region will be on local military installations?
- What limitations will regional land use patterns place on military installation activities?

Models that specifically address regional growth patterns over the course of many decades include CUF-2, SLEUTH, Smart Places, What If?, and LEAM. CUF-2 is the California Urban Futures model, version 2. This model employs a set of econometric models to project future population, household, and employment. The landscape is gridded into one-hectare developable land units (DLU). The value of each DLU for each competing land use is computed and land use change is based on comparing these relative prices. SLEUTH derives its name from the types of raster GIS data inputs: slope, land use, urban, exclusion, transportation, and hillshading (Clarke and Gaydos 1998). It is a cellular automaton model that updates the state of each cell in each time step based on the state of each cell and its immediate neighbors. LEAM, the Landuse Evolution and impact Assessment Model, takes a similar approach (Deal 2003). Using a 30 meter grid-cell cellular automaton approach, each cell is assigned a variety of development attractor values and the landscape evolves based on equations that assign future cell states based on the state of cells and their immediate neighbors. Smart Places is designed to be relatively easy to use by those familiar with ESRI's ArcView GIS as it is implemented as an extension to that system (EPRI 1999). What If? is a stand-alone product that used ESRI shape files (Klosterman 2001). Parcels are represented as entities using the ArcView shape files and they change through time based on the growth needs of the region, the state of the parcel and the state of its neighbors.

To be useful for projection, all urban growth models must be calibrated, which involves a process that can be time consuming and difficult. The SLEUTH model has been calibrated by testing thousands of combinations of coefficients using very fast computers. LEAM model calibration has been accomplished using a statistical technique (REF). These, and other models, can be run for a location using default calibrations and can be useful for educational purposes and for generating thoughtful conversation among stakeholders and other participants.

Many land use change models have been developed and are being used to test alternative land use policies with respect to their impact on future land patterns in and around cities and towns(EPA 2000). The Corps of Engineers is adopting the Land Evolution and Assessment Model (LEAM) to help evaluate how alternative regional policies and land ownership patterns affect future land development. The primary interest is to help minimize future land use conflict resulting from the development of new uses in areas that are and will be impacted by military training and testing activities.

3.3 Analyzing the Impact of Urban Patterns on Training and Testing Opportunities

Typically, the interactions among military and civilian land use are considered with the notion that the military activity changes more rapidly than the civilian land use patterns. Therefore, analyses generate patterns of dust, noise, smoke, or other impacts that can be

3.3.1 Noise Impacts

Perhaps the best-known and most common off-post impact of military training/testing is noise. Military noise can be generated from weapon firing, weapon impact and explosion, aircraft takeoff and landings, and various test activities. Military installations, airports, and other noise generating land use owners use computer modeling to understand and predict noise patterns.

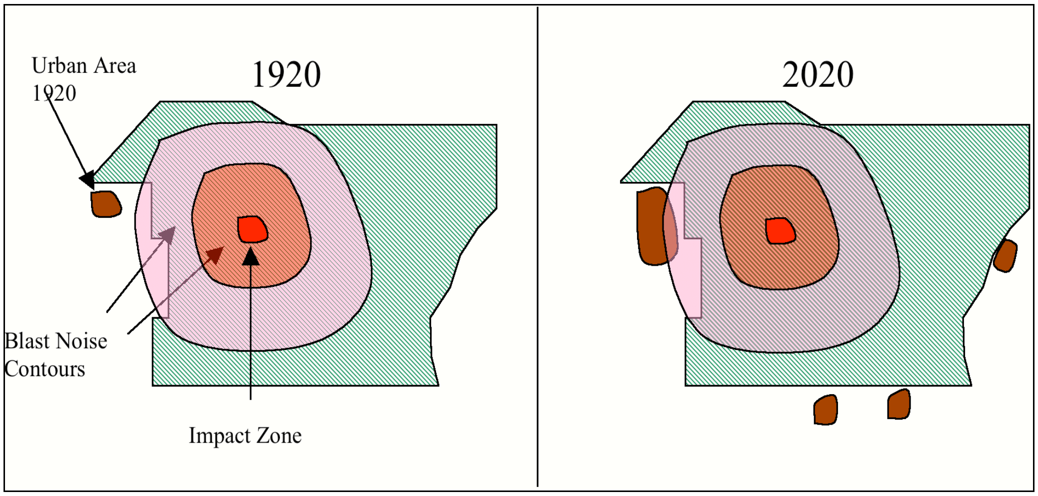


Figure 1: View of Urban Encroachment Impact on Noise Complaints

Consider Figure 1 above. A hypothetical 100 years of urban growth is represented for an installation with the current noise energy impact pattern overlaid. Over the century the original urban area has grown in size and three new urban centers have developed on the southern and eastern edges of the installation. The urban growth has pushed into noise levels that are likely to result in noise complaints and the installation is under pressure to change the timing and frequency of blast noise production. They may, in fact be considering moving the offending firing range to alleviate the problem.

Model outputs provide information about total noise energy, frequency of noise generation, and frequency pattern of the noise. Combining this information with human response data, it is possible to identify likely locations of people that are affected by the training/testing. Consider Figure 2. The left image shows Fort Benning (dark central area) and Columbus, Georgia (light area in the upper left). The center image represents anticipated noise levels associated with training and testing after construction of a proposed range. The right image is shows the overlap of the noise contours with land uses off the installation. Note the relatively low noise impact on Columbus, but a high noise level on lands just northeast of the installation. This type of analysis can be very helpful in understanding impacts of noise on neighbors and is conducted on a regular basis by CHPPM, the US Army Center for Health Promotion and Preventive Medicine.

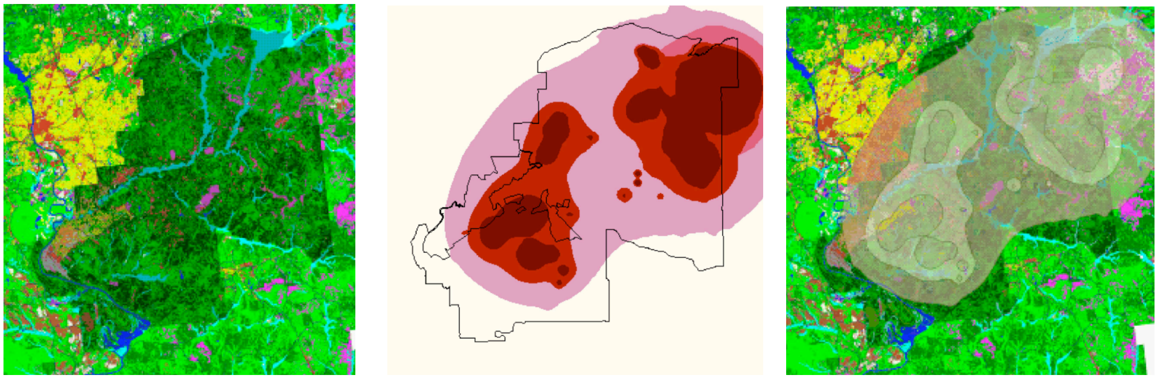


Figure 2: Projected Landuse and Projected Noise Contours

3.3.2 Dust Impacts

Many installations, especially those in desert and dry environments support training and testing that generate dust – especially from tracked vehicle maneuvers. Training and testing can also generate smokes and obscurants that can leave post and disturb local populations. Desert landscapes naturally develop a protective crust, often called desert armor, which resists further wind erosion. Bacterial and fungal mats can contribute to the cementing of this armor. Vehicle traffic readily disrupts this armor and immediately kicking up sand and dust that can be carried long distances by the wind. Disruption of the armor leaves scars that allow windstorms access to dust and sands that are no longer protected. Predicting the on and off-post footprint of sand in wind storms that result from training is as straight forward as predicting noise patterns, but no such models have yet been developed for military applications.

Dr. Jerry Allwine of DoE's Pacific Northwest National Laboratory (PNNL), uder SERDP project SI-1195 developed an ESRI based dust modeling system based on EPA-approved atmospheric dispersion models. EPA's Fugitive Dust Model predicts dust concentrations as a result of dust generation from a known or predicted event. Such models predict concentrations as a result of known release points, while our needs are to predict suitable release points based on known receptor sites.

3.3.3 Radio Frequency Interference Impacts

Radio frequency impact analyses associated with military training and testing can also be accomplished in a manner that is spatially explicit. However, federal laws and regulations and international agreements control the allocation of frequencies to various competing purposes, and it is this allocation that is eroding the freedom of the military to use the RF electromagnetic spectrum. The Objective Force is currently designed to be extremely dependent on the ability to monitor vast amounts of information in the battlefield through the application of electronic communication equipment. All means of electronic communication possibilities are being exploited and involve radio broadcast and reception over wireless, wire, and optical channels. Broadcast and reception involve all frequencies from almost 0 Hz to more than 300 GHz (wavelengths in the range of millimeters). At the lowest frequencies transmissions can go through the earth to communicate with submarines and aircraft on the opposite side of the earth. The highest frequencies are used to image things at great distances (the ground from satellite and objects from hundreds of miles away).

4 Materials and Methods

This project was conducted primarily through the development of computer-based information systems, simulation modeling, and geographic information systems. Success relied heavily on the ability to acquire and extract information from national, state, and local data sets.

4.1 Identification of At Risk Facilities

The purpose was to develop a procedure to identify installations at risk for future loss in mission support capabilities using nationally available data developed by various Federal agencies. Considerations include demographic, economic, and environmental indicators of risks to military lands. The risk assessment analysis identifies factors that serve as indicators of current and future risks for installations. Traditional statistical analysis is being incorporated with geographic information systems (GIS) to both perform the analysis and illustrate the findings. The overall methodology for this task considered five sub-areas:

1. Identification of a set of DoD properties to evaluate.
2. Selection of types of data to evaluate as potential risk indicators.
3. Gathering and preparation of data for evaluation.
4. Derivation of potential factors and assessment of their usefulness.
5. Identification of potentially at risk DoD properties from exogenous factors for further and more detailed analysis.

Identification and evaluation of types of data, known as installation risk factors or stressors, is complex. The effects of demographic change, community growth and sprawl, and regional economic vitality define levels of exogenous risk, or risk from outside the fence line. Issues associated with the mission of an installation, management, and cultural and natural histories define endogenous risk. The framework used in this project is highly structured towards the exogenous stressors, which have been determined with data sets available nationwide.

Our evaluation uses indicators to describe or represent the traits and processes of larger, complex systems to assess level of risk. Difficulty in selecting indicators is not due to a lack of measurable traits, but rather because of the overwhelming number of potentially useful indicators to choose from. This project uses the following International Institute for Sustainable Development's (IISD) criteria for indicator selection in order to assess indicator value and suitability:

Relevance: Can the indicator be associated with one or several issues around which key policies are formulated? The indicator must be linked to critical decisions and policies.

Simplicity: Can the information be presented in an easily understandable, appealing way to the target audience? Complex issues and calculations should yield clearly presentable and understandable information.

Validity: Is the indicator a true reflection of the facts? Was the data collected using scientifically defensible measurement techniques? Is the indicator verifiable and reproducible? Methodological rigor is needed to make the data credible.

Temporality: Is time-series data available, reflecting the trend of the indicator over time? Several data points are needed to visualize the direction the community or region may be going in the near future.

Measurability: Is the data quantifiable – something that can be measured directly or can be counted? Data must be based on tangible information.

Availability and Affordability: Is good quality data available at a reasonable cost or is it feasible to initiate a monitoring process that will make it available in the future?

Expansiveness: Is the indicator about a narrow or broad issue? Indicators that aggregate information on broader issues are preferred. For example, forest canopy temperature is a useful indicator of forest health and is preferable over measuring other indicators to come to the same conclusion.

Sensitivity: Can the indicator detect a small change in the system? Determine whether small or large changes are relevant for monitoring.

Reliability: Will you arrive at the same result if you make two or more measurements of the same indicator? Others should also reach the same conclusion.

Jenicek et al. (2002) describes a detailed description of terminology related to sustainability indicators for installation risk assessment and Fournier et al.. (2002) provides a detailed description of the framework used to select and develop the SIRRA installation sustainability assessment indicators.

4.2 Overview of Projecting Urban Growth and Their Impacts

Figure 3 provides a graphic overview of the steps involved in projecting the impacts of proposed regional plans on the long-term sustainability of military installations and their supporting regions.

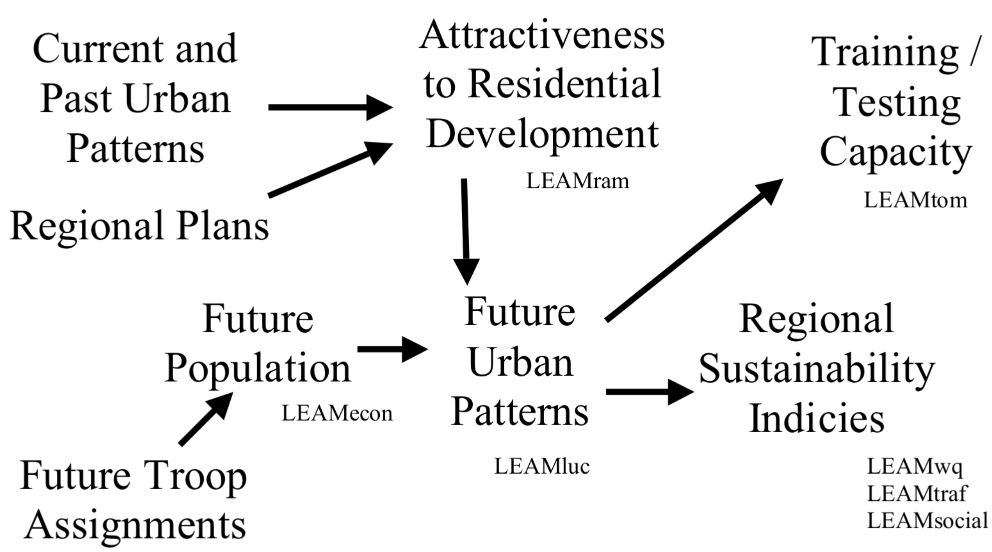


Figure 3: LEAM cause-effect relationships

The primary goal of this effort is to project the consequences of proposed regional plans on the long-germ sustainability of a military installation. Current and past urban patterns are used to

calibrate the ability to identify the attractiveness of all land parcels in a region to urban development. That development includes residential, commercial, and urban open space. This, combined with a proposed regional plan that includes construction of new roads, placement of new utility infrastructure, purchase of property and/or property development rights, and zoning restrictions, results in the production of a map that identifies the relative attractiveness of every parcel to new development. The resulting modeling software is called LEAMram, the LEAM residential attractiveness model. Development occurs in response to new housing requirements, which is based on population projections. Such projections can come from many sources, but for this project, we have adopted an economic input-output model that can turn future troop assignments into population projections based on the impact of the impacts of economic development induced by one sector on another, the LEAMecon model. With attractiveness to growth and projected population growth we are then able to project future urban patterns using the LEAM land use change (LEAMluc) model. Finally, the impact of projected patterns on military training opportunities (using LEAMtom), on water quality (LEAMwq), traffic congestion (LEAMtraf), and social indicators (LEAMsocial) can be estimated. The materials and methods used to develop these are discussed below.

4.3 Spatially Explicit Urban Growth Model

The LEAM land use change model, LEAMluc, has been developed to project land use changes within a set of counties (e.g. near military installations) as a consequence of spatial and dynamic interaction among economic, ecological, and control systems in the region. The LEAMluc approach is unique in that systems are explicitly and separately modeled in a collaborative design of initially independent sub-models. These are developed by groups or individuals who have substantial knowledge of a particular component or function of the overall system. The sub-models are then linked to form the main framework of the dynamic model, which runs simultaneously in each grid cell of raster based GIS map(s). We initially developed LEAMluc using STELLA, a commercial simulation model development system and the general-purpose, Spatial Modeling Environment (SME), developed at the University of Maryland. STELLA allowed specialists knowledgeable of the dynamics of urban development, but without any particular computer programming skills to capture their understanding of the processes within a graphical simulation model development environment. SME converted the models developed in STELLA into C++ computer programming language software, which compiles on various computers – including supercomputers. The result is that we were able to create and share modular, reusable model components, and utilize advanced parallel computer architectures without having to invest unnecessary time in computer programming or learning new systems. Once LEAM modeling stabilized we used leveraged funding from the Common High-performance Software Support Initiative (CHSSI) to directly capture LEAMluc in the C programming language and achieve dramatically faster execution speeds. This allowed us to abandon the slower, but more flexible SME environment.

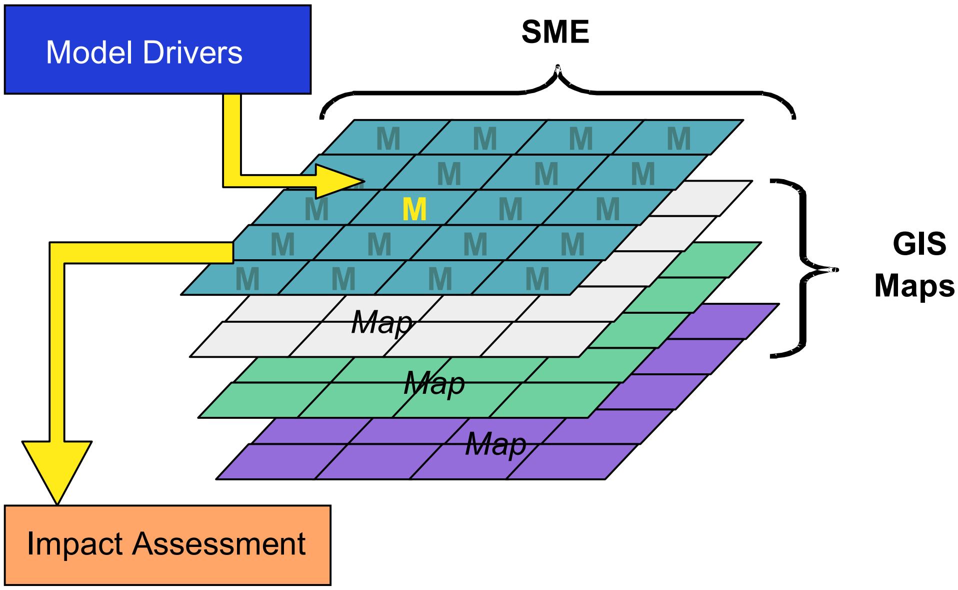


Figure 4: Model drivers (independent models) are linked in a GIS layered environment to synthesize a predicted future outcome in the LEAMluc process

The fundamental LEAMluc approach to capturing land use transformation dynamics begins with model drivers. Model drivers are considered those forces, typically human, that contribute to urban land use change. The model drivers describe transformation probabilities; the simulation realizes those probabilities in the development of a landscape; and the resulting simulated land use change is then analyzed for impacts and creates sustainable indices that can affect future training and testing capacities (Figure 3).

This work made use of the ESRI ArcGIS software, the "C" programming language, the Spatial Modeling Environment, and personal Windows XP computers and a variety of supercomputers at the ERDC MSRC site and the University of Illinois.

4.4 Impact Assessment of Urban Development

4.4.1 Environmental Impact Assessments and Criteria Developments

Impacts of projected urban patterns on regional environmental, economic, and social factors have been researched and developed. This particular research was completed early in response to the June 2004 SERDP TTAWG guidance that shifted the focus of the research from this impact assessment to direct military impacts. Information from these impacts assessment models can influence policy strategies inside and outside the fence-line that would promote more sustainable land use scenarios. Areas of explicit concern include impacts such as water quality, water quantity, resource depletion, threatened and endangered species, and habitat destruction and fragmentation, affects on the regional economy, traffic congestion, fiscal impacts, and social/demographic changes. This work was primarily conducted using the ESRI ArcGIS software running on Windows XP computers.

4.4.2 Future Training/Testing Opportunities

The ultimate goal of this project was to develop and test processes that can be used to predict the impact of alternative regional planning scenarios on future land use changes around military installations and then evaluate those predictions with respect to subsequent limitations on training.

Originally, we set out to develop simulations to predict the future layouts and configurations of military installations in a manner similar to our off-installation urban growth models. We argued strongly that it is impossible and unwise to project the future use of military installations and their land use patterns (Westervelt, 2004). Urban development off installations is the result of hundreds or thousands of land and house purchase decisions by many individuals. It is virtually impossible to predict where each new prospective homeowner will purchase a place to live, but it is reasonable to project the land use patterns based on hundreds or thousands of purchases. The use of installations and the pattern of installation land use is based on a relatively small number of decisions and is unpredictable as any single home buyer's decision. Predicting the use of installations, for example, would need to begin with predicting future Base Realignment and Closure (BRAC) decisions – a politically tricky business indeed.

Instead, we turned our attention to predicting the training/testing opportunities that remain after projected urban growth. Specifically, we developed spatially explicit analysis procedures to convert maps of urban patterns (historic, current, or predicted) to maps showing locations where the local projected residential areas will tolerate impacts of training and testing (in the form of noise, radio interference, and dust) and where night lights from urban areas will not interfere with night training.

This work was accomplished using the open-source GRASS geographical information system running on a LINUX computer and developing new software using the "C" programming language.

5 Results and Accomplishments

The results and accomplishments are here discussed in three sections: 1) the SIRRA tool and its ability to identify at-risk facilities, 2) the urban growth tools including LEAMram and LEAMluc, and 3) the models that evaluate the impact of projected growth, which include LEAMtom, LEAMtrans, LEAMwq, and LEAMfiscal. These are followed by descriptions of the test application of the tools at Scott AFB and Fort Benning.

5.1 Identification of At Risk Facilities

This aspect of the project has attracted significant outside interest and funding primarily because of the usefulness of the effort to the current Base Realignment And Closure (BRAC) efforts. Fifty-four sustainability indicators (grouped into ten categories) were collected at the national scale for this project (Table 1). The prototype SIRRA web site has been established as a permanent stand-alone system housed at the ERDC web farm in Vicksburg, Miss and connected to the CorpsMap map server developed by the Cold Regions Research and Engineering Laboratory (ERDC-CRREL). The SIRRA methodology has been adapted to incorporate weighted indicators based on mission type. The result of the 54 individual indicators is summed to give a relative sustainability vulnerability ranking to 309 DoD installations. The results of this are described by Fournier, et al. (2002).

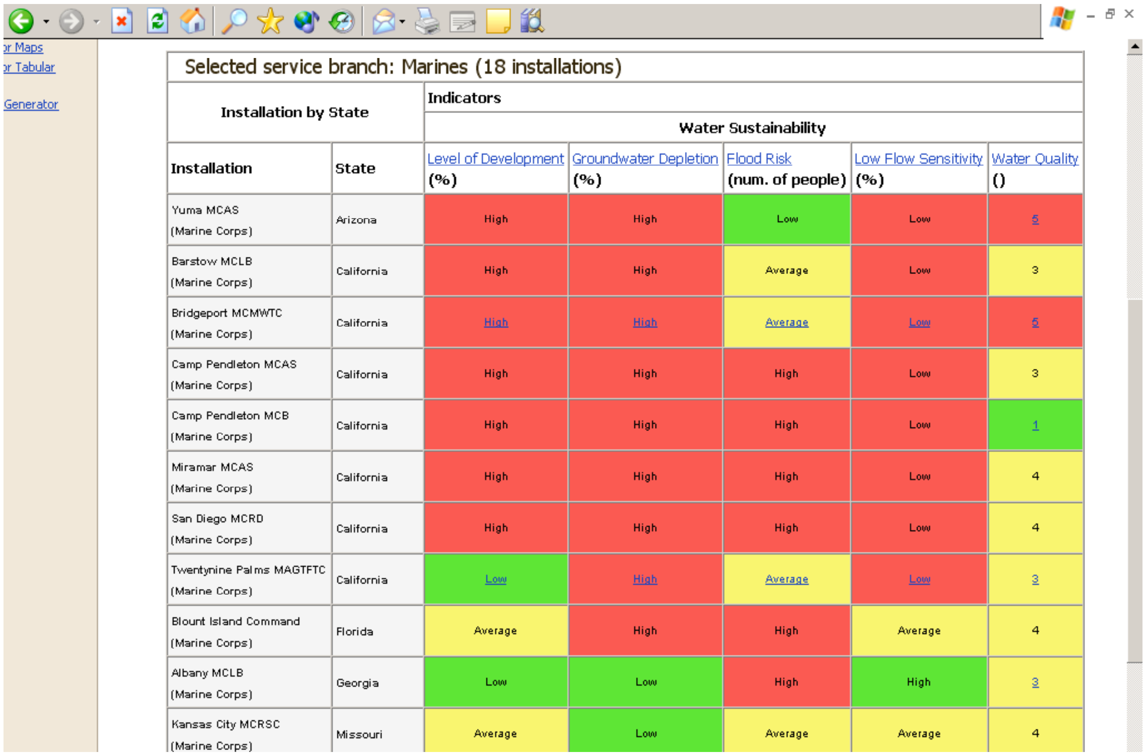
Table 1: SIRRA Issues and Indicators

Issue	Indicator	Latest Update	Data Source	Data Level
Air Sustainability	Criteria Pollutant Non-Attainment	2003	EPA	county
	Noise Sensitivity	2000	USCB	installation
Energy Sustainability	Electrical Grid Congestion	2004	NERC	NERC Subregion
	Electrical Reserve Margin	2003	NERC	NERC Region
	Wind Resources	1986	NERL	solar grid unit
	Solar Resources	1992	NERL	wind grid unit
	Biomass Resources	1999	NERL	state
	Electrical Price Structure (Deregulation)	2003	EIA	state
Urban Development	Regional Population Density	2003	USCB	county
	Incr. Regional Growth Rate	2003	USCB	county
	Regional Population Growth	2003	USCB	county
	Regional Land Urbanization	1992	NLCD	installation
	State Smart Growth Plans	2002	APA	state
	Joint Land Use Study (JLUS)	2003	JLUS	installation

TES Sustainability	TES by State	2004	FWS	state
	Species at Risk	1990	JAWRA	watershed
	Federally Listed TES	2004	NatureServe	ecoregion
	TES of Concern	2004	NatureServe	ecoregion
Locational Sustainability	Federally Declared Floods	2004	FEMA	county
	Seismic Vulnerability	2002	USGS	zone
	Weather-Related Damage	2003	NWS/NOAA	state
	Federally Declared Disasters	2004	FEMA	county
	Tornadoes	2002	NOAA	county
Water Sustainability	Level of Development	1990	EPA	watershed
	Ground Water Depletion	1990	EPA	watershed
	Flood Risk	190	EPA	watershed
	Low Flow Sensitivity	1990	EPA	watershed
	Water Quality	1990	EPA	watershed
Economic Sustainability	DoD Local Employment	2002	REIS	county
	Job Availability (Unemployment)	2003	BLS	county
	Housing Affordability	2000	USCB	county
	Poverty	2000	USCB	county
QoL Sustainability	Crime Rate	2001	NACJD	county
	Housing Availability	2000	USCB	county
	Rental Availability	2000	USCB	county
	Healthcare Availability	2000	HHS	county
	Educational Attainment	2000	USCB	county
	Commute Times	2000	USCB	county
Infrastructure Sustainability	Capacity of Commercial Airports	2002	TAF	installation
	Airport Suitability C5	2001	FAA	installation
	Airport Suitability C141	2001	FAA	installation
	Railroad Capacity	2004	FRA	county
	Proximity to Interstate	2003	IRRIS	installation
	Roadway Congestion	2002	FHWA	state
	Traffic Volume	2002	TTI & FHWA	state
Security Sustainability	Air Space Demand	2003	--	installation
	Net Metering	2003	Green Power Network	state
	Proximity to MSA	2003	USCB	installation

Leveraged funding provided for the creation of the Internet browser based utility called the Sustainable Installation Regional Resource Assessment (SIRRA) tool. The SIRRA web site was put through a thorough review by representatives of all services during January and February of 2004 and was released in July 2004. It is now deployed as part of the ERDC Fort Future system (https://ff.cecer.army.mil/ff). Users can select a subset of the 309 installations and a subset of

the 10 groups of indicators (e.g. Figure 5). National maps of indicators are available to allow visualization of the regional context of any selected installation (e.g. Figure 6).



Selected service branch: Marines (18 installations)						
Installation by State		Indicators				
		Water Sustainability				
Installation	State	Level of Development (%)	Groundwater Depletion (%)	Flood Risk (num. of people)	Low Flow Sensitivity (%)	Water Quality ()
Yuma MCAS (Marine Corps)	Arizona	High	High	Low	Low	5
Barstow MCLB (Marine Corps)	California	High	High	Average	Low	3
Bridgeport MCMWTC (Marine Corps)	California	High	High	Average	Low	5
Camp Pendleton MCAS (Marine Corps)	California	High	High	High	Low	3
Camp Pendleton MCB (Marine Corps)	California	High	High	High	Low	1
Miramar MCAS (Marine Corps)	California	High	High	High	Low	4
San Diego MCRD (Marine Corps)	California	High	High	High	Low	4
Twentynine Palms MAGTFTC (Marine Corps)	California	Low	High	Average	Low	3
Blount Island Command (Marine Corps)	Florida	Average	High	High	Average	4
Albany MCLB (Marine Corps)	Georgia	Low	Low	High	High	3
Kansas City MCRSC (Marine Corps)	Missouri	Average	Low	Average	Average	4

Figure 5: Sample SIRRA tabular report

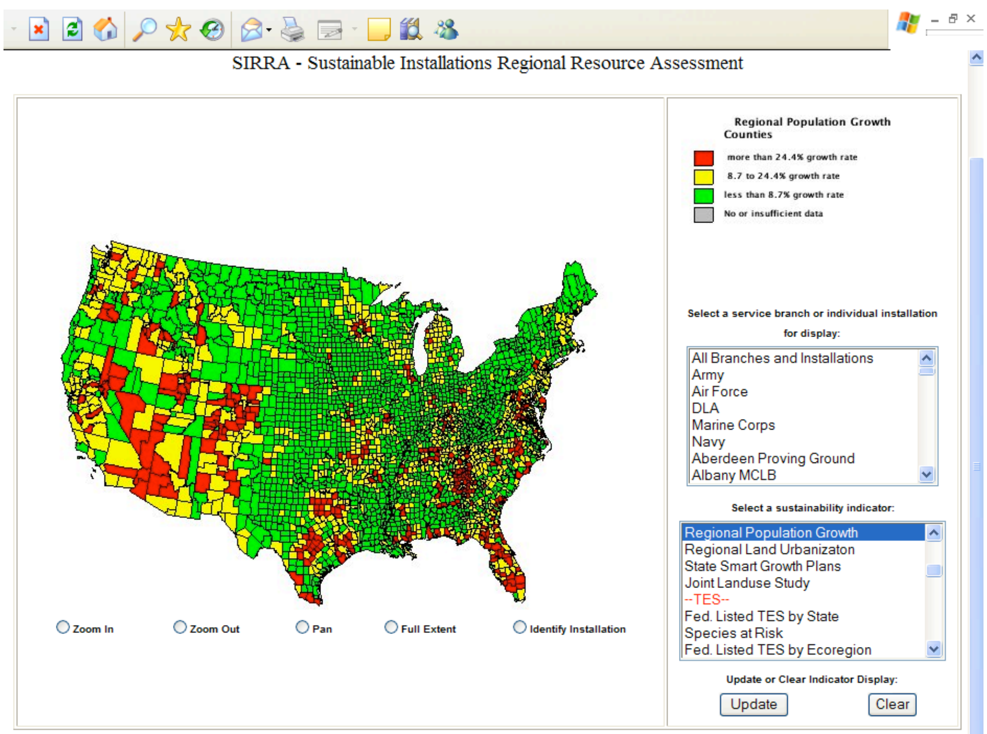


Figure 6: Sample National Map Available through SIRRA

The SIRRA methodology has been adapted to provide sustainability vulnerability ratings based on watersheds rather than installation boundaries.

The SIRRA database has also allowed the rapid execution of studies of specific areas. For example, reports have been generated for Rattlesnake Training Grounds in Montana and Fort Stewart, GA.

SIRRA was briefed at the Federal Planning Division meeting of the American Planning Association in March 2005 and was demonstrated at the Joint Services Environmental Conference in April 2005.

Applications of SIRRA include:

- Global Restationing. 2004, a study of potential regional impacts related to the Army's global re-stationing initiative
- Range and Base Siting. 2004, analyze the location of a new bombing range in the western U.S.
- Watershed Sustainability Analysis. 2005, SIRRA was modified to compare and analyze sustainability issues for watersheds nationwide,
- Vulnerability Ranking of DoD Installations. 2005, SERDP sponsored ranked set of 308 DoD installations.
- NEPA Screening Tool. Assist in scoping of NEPA analyses.
- Range Encroachment Analysis. 2005, OSD Sustainable Ranges program.
- Facility Sustainability Comparison. 2006, NASA to compare triple bottom line issues around their U.S. based facilities.

Using leveraged funding, SIRRA was upgraded in FY05 to allow automatic computer-to-computer updating of many of the data base components through coordination with various federal data development offices.

SIRRA is publicly available at: https://ff.cecer.army.mil/ff/sirra.do

5.2 Spatial Explicit Urban Growth Model

5.2.1 Quick and Dirty Residential Attractiveness Model (LEAMram)

The LEAMram analysis fills a need for a rapid identification of the attractiveness of land around military installations to residential growth – development that is perhaps the least compatible with military training and testing. LEAMram uses as inputs readily available maps that can be freely downloaded off federal Internet sites:

- Digital elevation model
- National Land Cover Data (NLCD)
- Roads and highways (Tiger files)

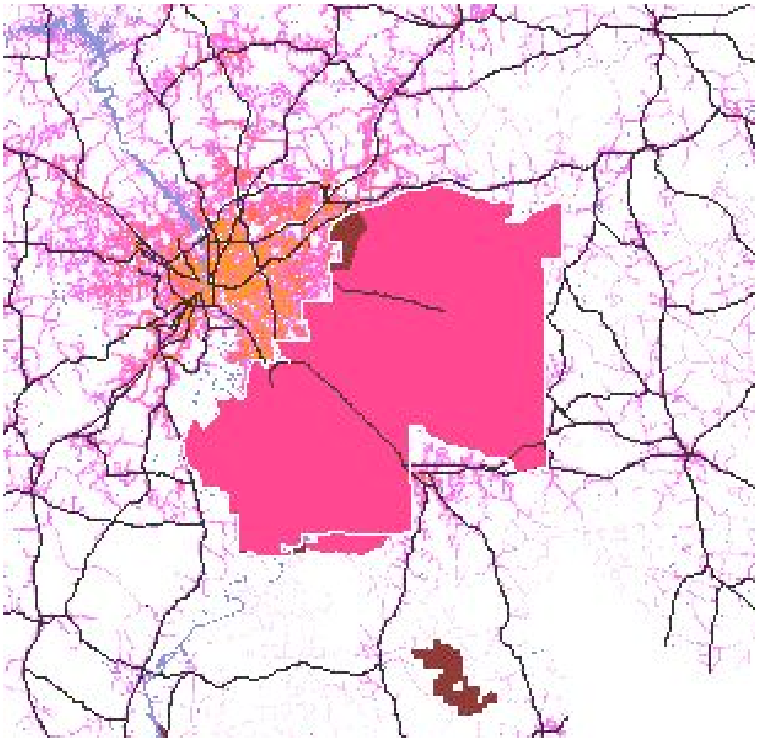


Figure 7: Sample LEAMram Analysis Results of Fort Benning

The automated GIS scripts use the freely available GRASS GIS to generate intermediate maps that identify business centers, residential centers, forest and water locations, intersections, highways, roads, and interstates. Travel time access for every map location to these locations are calculated and then compared with the densities of urban areas at different travel times to correlate urban attractiveness with these times – and also with land slope. The strength and magnitude of these correlations are then combined for every location to generate a residential attractiveness map. The process is self-calibrating in that the strengths of correlation are computed for each location as part of the self-running script.

Figure 7 shows results of a sample analysis of the Fort Benning region. The pink area in the center is Fort Benning and solid brown areas in the rest of the map are other federal lands. Highways are shown in black. In the white areas, fewer than 1 percent of the land is classified as residential; pinkish areas are about 10-20% residential and orange areas (e.g. the center of the main city to the northwest of then installation (Columbus) are about 50% developed as residential. Figure 8 shows some of the interim residential attractiveness maps associated with nine individual attractors. Maps that are predominately one color demonstrate relatively low correlation with residential density (e.g. forest, water, and slope), while other maps with higher variability show higher correlation. Figure 7 is a combination of these nine attractor maps with those with higher correlations having a higher impact on the overall attractiveness.

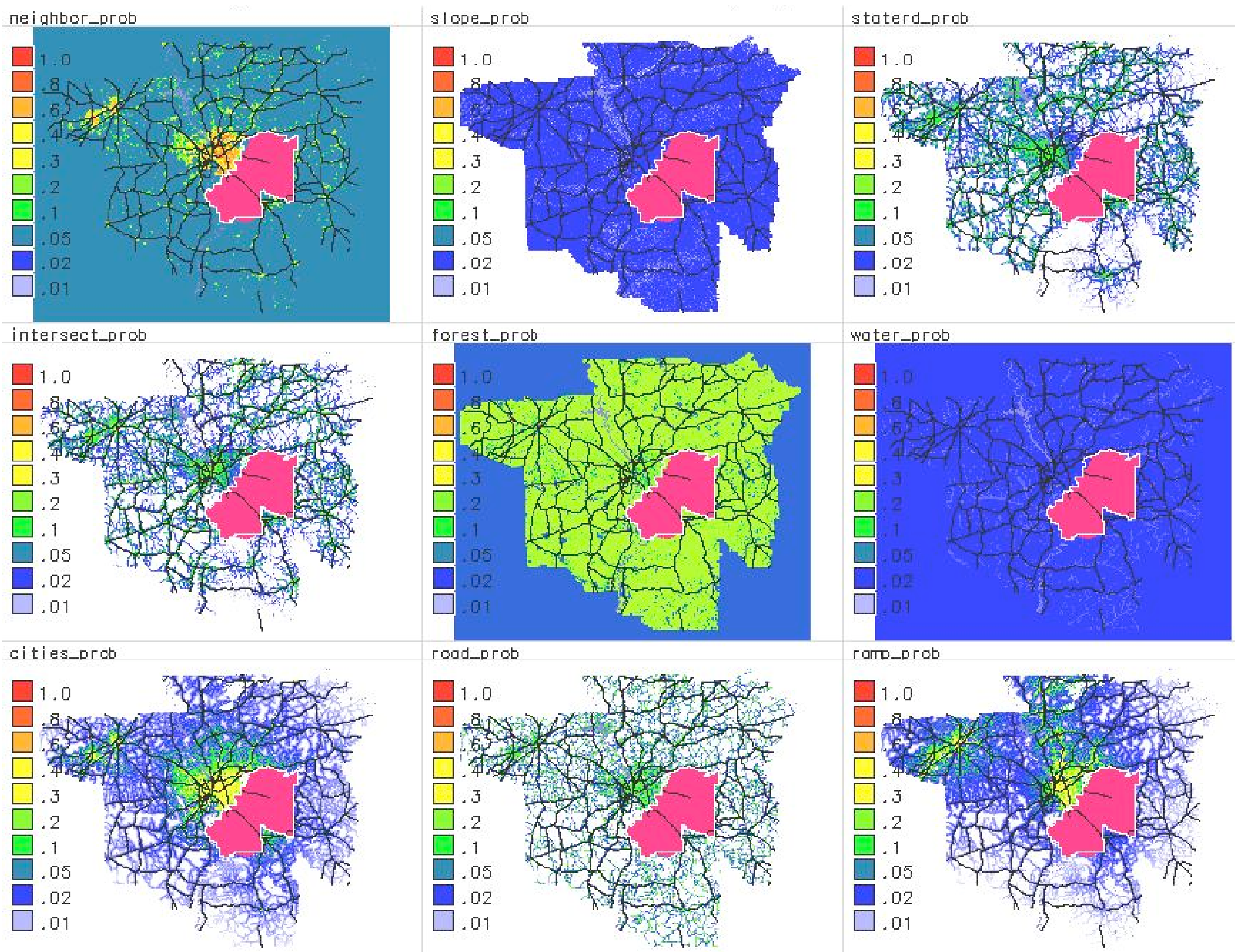


Figure 8: Sample LEAMram Interim Results

Being relatively quick and easy (one to two days of GIS technician and computer operator effort for an initial analysis), we have been able to apply this model to the locations in

Table 2: Sample LEAMram Analysis Locations

Camp Atterbury, IN	Fort Lee, VA
Fort Belvoir, VA	Norfolk Area
Fort Benning, GA	Fort Polk, LA
Fort Bliss, TX	Fort Riley, KS
Fort Bragg, NC	Scott Air Force Base, IL
Fort Carson, CO	Fort Sill, TX
Fort Eustis, VA	Champaign County, Ill
Fort Gordon, GA	Kishwaukee River, Ill
Fort Jackson, SC	29 Palms Area, CA
Fort Knox, KY	

The techniques behind this LEAMram analysis were submitted as a journal article with the title “Rapid Analysis of the Attractiveness of Land to Residential Development” to the Journal of Military Operations Research (JMOR).

5.2.2 The LEAM Land Use Change Model (LEAMluc)

Significant development and redevelopment of the LEAMluc model has focused on improving population projections, model execution times, accuracy, calibration and consideration of more land use change drivers.

Refinement of LEAMluc

Land Cover Data Analysis

Several techniques have been developed to verify the base year land cover maps used to run the model for the Scott Air Force Base region. Combining several data sets produced the final LEAM Illinois base-map. The 1993 USGS NLCD data was first merged to the 2000 Illinois data to update urban land uses and reclassify errant cells. The 1993 USGS NLCD classification coding system was adopted as the final coding system. Road networks were then overlaid onto the map with a new classification designation. A methodical manual process of localizing and verifying the resulting map was then undertaken. This work was completed by regional planners using aerial photos, available local maps, and personal knowledge about the region. The final steps toward base-map production include the calibration of the now updated map to available 2000 census data.

To help verify the 2000 base data map. Census data was compared with mapped data at the block level. In Illinois, large amounts of random development (noise) initially existed in the map. Census data reveals from 1993 to 2000, just over 9,000 people were added to the region. Our base-map shows 16,000 new residential cells over the same time period. In Missouri, large amounts of densely developed tracts, have consumed all developable areas. In the region from 1993 to 2000, 500,000 new residential cells were found with only 60,000 new people. Although some of this can attributed to migration out from the city center, by comparing populations and households in each census block with the number of cells present in 2000, we could assess how many developed cells should be present to satisfy census calculations. This was done in 3 steps:

- Step 1: Clean up residential cells outside the municipal boundaries or their buffers (1 mile for municipalities with populations greater-than 2000; 1/4 mile for those with populations less than 2000). This clean-up effort helped to reduce the inaccuracies of the total Illinois cell count (from 160,000 unaccounted for cells, to 123,000).
- Step 2: Since rural development outside of a 2 mile municipal buffers is an exception rather a rule, removing all rural development that shows up in the 2000 data that is not present in the 1993 data will enhance the accuracy of the base data set. In Illinois, the number residential cells were reduced to 84,000 (40,000 cells were removed), bringing the total much closer to 2000 census results.
- Step 3: Compare LU data to census data,
  - Remove any residential cells from the 1993-2000 difference map in census blocks where 2000 census population growth is negative or zero. (267,000 cells removed - 76,000 in IL (Figure 9) - almost 200,000 cells in MO).
  - Ignore small or sparsely populated census blocks where the cell to population ratio is less than 2.0

- For all other census blocks, compare the remaining 2000 LU residential cell counts with 2000 census population data.
  - Increase or decrease the number of cells required to satisfy census counts.
  - Use LEAM probability maps to place the required cells within the census block.
  - Cells with the highest development probabilities remained classified as developed.

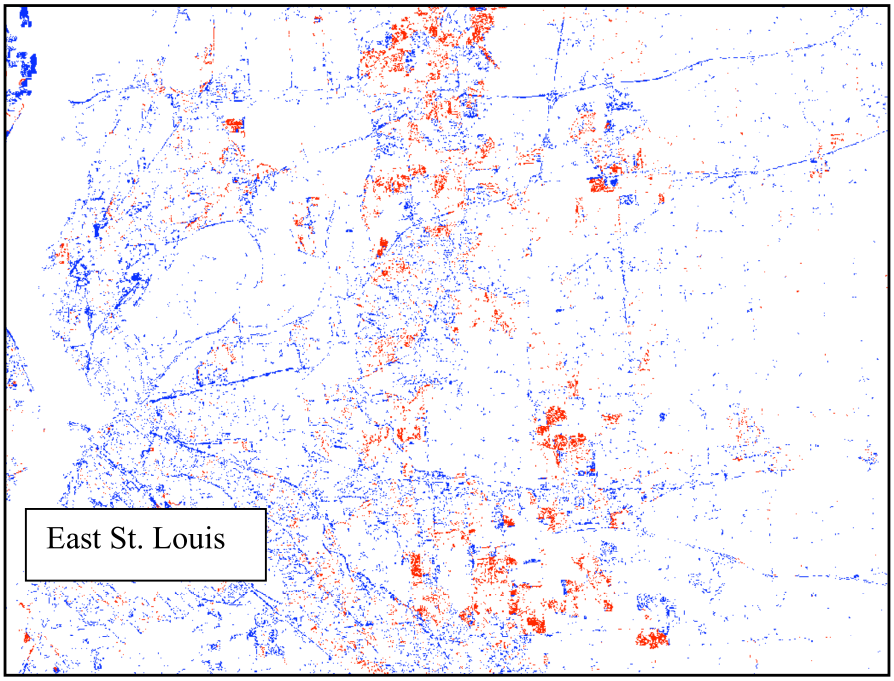


Figure 9: A sample map depicting changes in the IL base map when noisy satellite data is cleaned. Blue cells remain classified as developed; red cells reclassified as undeveloped.

Figure 9 is a sample map depicting changes in the IL base map when noisy satellite data is cleaned using a 2 mile municipal buffers as an exception and removing all other rural development that shows up in the 2000 data that is not present in the 1993 data. Blue Cells are 2000 data representing development. Red cells have been reclassified as undeveloped.

Residential Land Demand

In previous versions of LEAM, the assumed relationship between population growth and demand for land was simply assumed on historical levels of people per acre, typically around 1 person per cell. However, this approach tends to underestimate the amount of development that will occur in the future because it does not account for other factors of urban growth such as declining household size, increasing lot size, and intra-regional movement (vacancy and abandoned housing). When applied to the Scott AFB, land demand is significantly larger than our initial simplified approach. In our initial approach, we assumed the 88,000 increase in population projected for the region over the next thirty years would lead to 22,000 acre of residential development (88,000 30m x 30m cells). Under the new approach (Figure 10), accounting for the effect of declining household size, increasing lot size, vacancy, and housing

units lost, over 100,000 acres of residential development is project to occur. The most critical factor is housing units lost (abandonment). Historically in the Scott AFB region, there has been a close to 1:1 ratio of housing units lost/increase in households. We assumed a much more conservative amount of abandonment over the next thirty years, but it still accounts for a large portion of the demand for new residential housing (over 50%). This new approach to determining the amount of residential development over the next thirty years is much more realistic and consistent with historical trends than the initial approach and will have a significant impact on the results of future simulations.

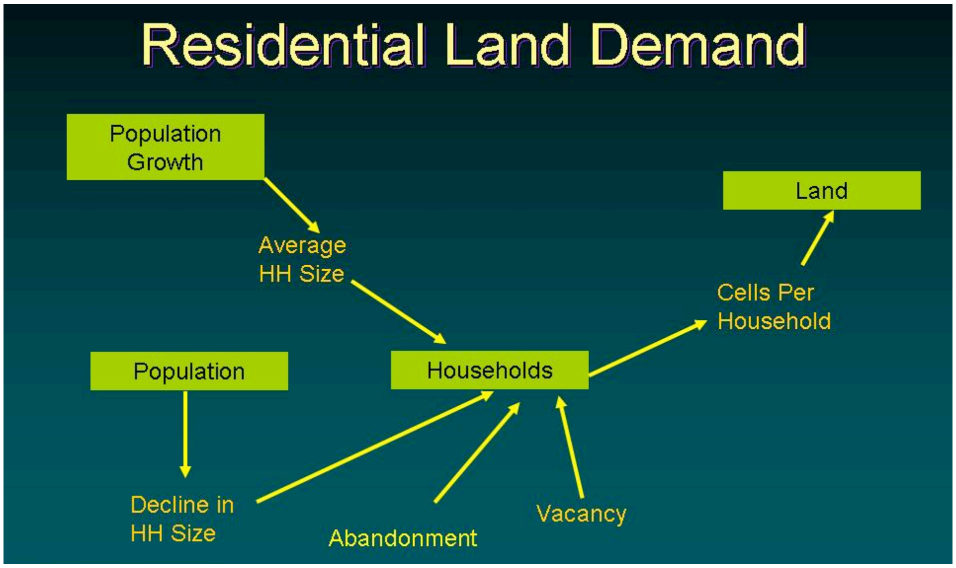


Figure 10: Key Factors in the Demand for Residential Land

5.2.3 Backcasting LEAMluc to Verify Results

An important point of emphasis from the SERDP Technical Committee in their 2006 review was the ability to verify that the projections from LEAMluc are comparable to historic data. One method of verifying the projections that come from LEAM is to "backcast" or run the model during a historical time period in which data is available and compare the forecasted results to the actual historical trends. However, due to the lack of historical landcover data (the earliest available consistently developed data for the US is 1992), it is not currently practical to backcast LEAM. To calibrate and then test LEAM, three consistently developed landcover maps for the study area must exist. When LEAM was initially proposed, the USGS had successfully completed a consistent land cover map (1993 NLCD) for the entire United States at a resolution of 30 meters and was in the process of developing the next set (2002 NLCD). Unfortunately, budget cuts forced USGS to 1) dramatically slow the process, and 2) apply an inexpensive, but very different process that resulted in 2002 data that was not consistent with the 1993 data. Therefore the LEAM project was left without the anticipated consistent 1993 and 2002 national data sets that could be used to calibrate the model. In response, the project attempted to adapt satellite image processing capabilities so that a time-series of imagery could be consistently processed for any given area, but discovered no sufficiently inexpensive approach. The state of Illinois generates a state-wide landcover data set at a cost of at least 3 person-years of effort to complete the development of one map. We determined that development of a suitable landcover map for an area such as Fort Benning would cost $100-200K. Three such maps, to allow

calibration and backcasting, would cost triple that amount. Note that the RSim effort, headed by Dr. Virgina Dale, had an effort that focused on the Fort Benning area only. A time-series of land cover maps were being completed by the University of Georgia funded by the Turner Foundation, the USGS, the Georgia Department of Natural Resources, and the Sapelo Foundation. The RSim effort availed themselves of this substantial investment, while the LEAM effort sought to develop a process that could be affordably duplicated anywhere in the US.

The LEAM Lab verifies results by conducting a human-intensive calibration process, working closely with local stakeholders such as local planners, who have a good understanding of how the region has grown in the past and issues it faces in the future. At each stage of development, from preliminary runs to a localized model, LEAM results are provided to local stakeholders to review and critique. The LEAM Lab takes the information from the local's critiques and tries to address any issues with the results by doing more in-depth analysis of the simulation results to understand why the model results are counterintuitive, or add other data or adding a new driver to the model to more accurately project future growth.

5.2.4 Development of Spatial Frequency Analysis

Spatial Frequency Analysis is a sophisticated way of calibrating land use change drivers in LEAM (Figure 11). In LEAM, the objects that drive new development around them are called 'development attractors.' For example, main roads and ramps, existing developed areas, and utilities are development attractors in LEAM because new development is likely to occur in their vicinity.

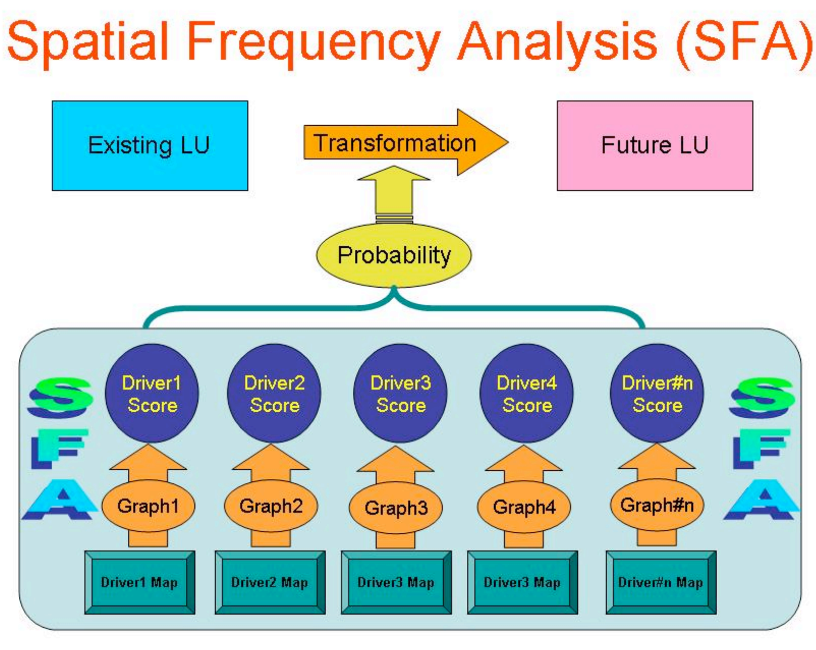


Figure 11: The Spatial Frequency Analysis/LEAM Framework

For each type of development attractor, a raster GIS map is generated in which a score is assigned to each cell in the region. This 'development score' is a function of proximity and is computed based on the cumulative travel time from the concerned cell to the nearest (development) attractor cell. Based on the map containing development scores, how existing and new urban developments are related to attractors is analyzed. There are three steps to this

analysis. The first step is to develop a map, called an attractor map, for a particular type of attractor, containing development scores with respect to each attractor. The second step is to evaluate the frequency of urban development that is found in cells within a given time from an attractor. The third step is to estimate development score with regard to each attractor map. Figure 12 is an example of the result of this analysis – a proximity map of development to interstate ramps in the Scott Air Force Base region.

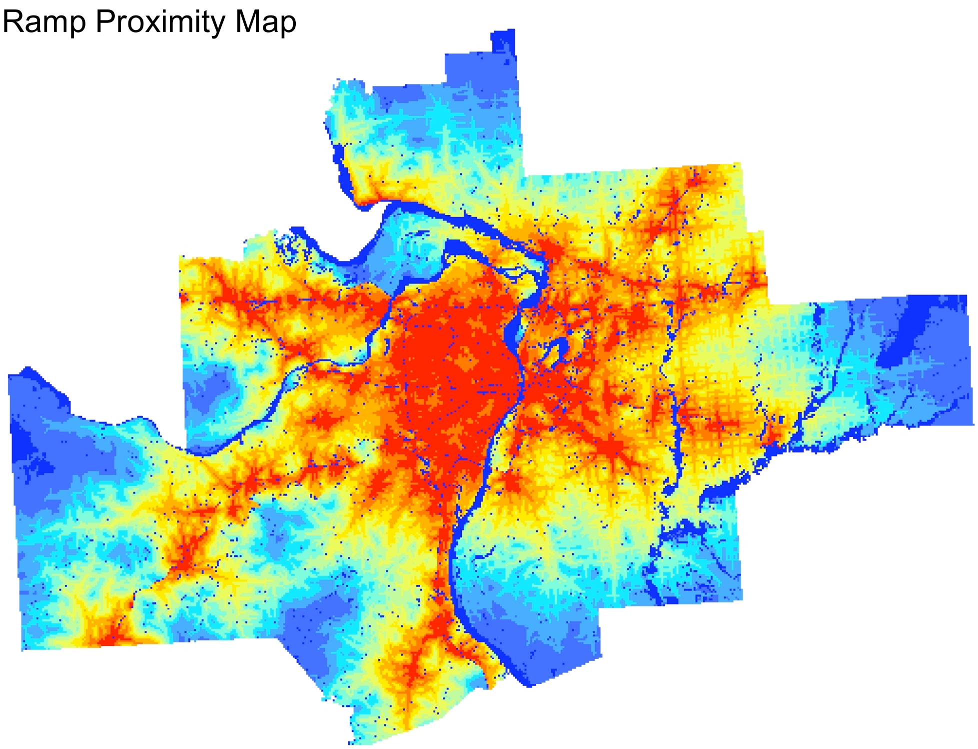


Figure 12: Example of Spatial Frequency Analysis: Ramp Proximity Map

5.2.5 Input/Output Economic Driver Implementation (LEAMecon)

The economic model in LEAM (LEAMecon) forecasts changes in output, employment and income over time based on changes in the market, technology, productivity and other exogenous factors. The resulting economic trend is used as an input to a dynamic housing market simulation that then feeds into LEAM as residential land-use change. The agent-based housing model predicts actual houses built in a given year based on trends in the economy and anticipated demand by specific population cohorts. The combined economic and housing model serves as a prime driver of land-use change. Through LEAM, this work connects knowledge in regional science, housing markets, and spatial land-use analysis.

LEAM modeling exercises simulate different scenarios involving alternative growth patterns based on regional and national changes (government policy, tax structure, new markets, changing demands etc). Scenarios are answers to 'what if' questions that together make clearer the decision choices available to a region. For example, alternative investment decisions can be modeled as different scenarios to see their impact on the regional economy and land-use. Scenarios are also a way to model shocks to the system. Shocks include local events such as closing a military base, as well as local responses to external policy changes, such as changes in

the tax on gasoline. Shocks can be induced at a point in time or spread out over a period like investment in highway construction over 5 years. Consistent demographic and economic forecasts under different scenarios enable LEAMecon to model alternative demands on residential and commercial / industrial growth over time in the region. This strengthens LEAM's capacity to provide answers to a wide range of 'what-if' policy questions.

Coupled Input – Output Econometric models provide a wide array of impact analysis and forecasting abilities. When a model is run for a period of 30 years, many structural changes are expected to occur in the economy including changes in production structure, consumption behavior, etc. To capture such dynamics, I-O models are integrated into wider dynamic modeling frameworks. In a computable general equilibrium framework, the coupled model accounts for equating supply and demand sides of each commodity in the market. This is true for matching labor demand and supply through migration patterns, changes in unemployment levels, labor force participation rate, etc.

The core model consists of nine economic sectors and nine components of final demand. The output from each sector is consumed by other sectors (inter industry flows) and by components of final demand (which characterizes value added in the economy). The model consists of five modules of equations for each industrial sector and an additional module for demographics variables. The first module is the input output module that captures flow of goods and services inside the region, their destination to final demand and exports outside the region. To overcome the static nature of Input Output model, it is coupled with an econometric framework, where output, employment and income corrections due to changes in technology, productivity, etc., are made in three different modules. The fifth module endogenizes the dynamics of final demand and provides feedback into the production cycle. The final or sixth module is the demographic model that balances labor force demand and supply mechanisms. All the modules are solved simultaneously to completely forecast regional economic indicators that are used as input to other sub-models in LEAM.

Table 3: LEAMecon Variables forecasted

Economic Variables	Demographic Variables
Gross Regional Product	Population by age cohorts
Consumption by households	0-4 School age
Private Investment	5-14 School age
Federal government	15-14
Non defense purchases	15-24 Active labor force and population in driving age
Defense purchases	25-44 Active labor force and population in driving age
Investment	45-64
State and local government	65+ Retired population
Education	Components of population change
Non education	Births
Investment	Deaths
Personal Income	Net migration
Residential adjustment of income	Labor Force
Contribution to social security	Percent of resident workers
Income from dividends, rent, etc	Percent of non resident workers
Transfer Payments	Unemployment rate
Per capita personal income	Average wage and by industry
Output, employment and earnings: Total and disaggregated by industry	

Table 4: List of LEAMecon Economic Sectors

Economic Sectors
Extractive (agriculture and mining sector)
Construction
Manufacturing
Transportation, Communications and Public Utilities
State and Local Government Enterprise
Retail Trade
Wholesale Trade
Finance, Insurance and Real Estate
Federal Government Enterprise

The model described above provides consistent economic and demographic variables for the region (Table 3). Various shocks like investments to specific sectors (listed in Table 4), increase in public spending or consumption from households, etc., can be applied to the regional economic system. The employment model shows changes in productivity over time to determine regional employment levels. The percentage of workers living outside the region and commuting to work on daily basis is used as a policy variable to model effects of income leakages from the region. The income module models regional average wages in response to interaction between labor demand and labor supply. The average wages are converted into industry specific wages and total regional income is computed. Personal income is derived from wages and salary income after accounting for other components such as contributions to social security, transfer payments, etc. The income leakage due to daily commuting is modeled in this block. Finally, differences in labor demand and supply affects net migration. If the employment demand increases relative to labor supply from households, the regional unemployment rate decreases until people migrate into the region and equilibrium is reached. These dynamics occur with different time lags in different parts of the model. Population change is modeled on births, deaths and net migration. The total population is sub divided into different age-cohorts, each of which has a specific role to play in regional land use change, evolution and impact assessment in the region.

The economic driver model used in LEAM captures causal mechanisms and not just patterns of changes and impacts. The forecasts generated are consistent with local conditions and all coefficients are region specific. It also provides an opportunity to model economy related shocks to the region and evaluate alternative 'what-if' possibilities. In addition to predicting consistent interdependent economic and demographic variables, its transparent structure helps to trace the propagation of shock through the system and present a clear picture of the regional dynamics providing useful information to Land-use Evolution and Impact Assessment Model.

One example of a "what-if?" economic scenario that was analyzed was the closure of Scott Air Force Base in the St. Louis region. The process of base closure is assumed to begin in the year 2010. A total of 13,000 jobs will be lost from the federal payroll between 2010 and 2011. This will also mean out-migration of about 35,000 people directly engaged with base related activities from the region during the same period. This scenario was modeled against a business as usual case.

The region would loose a total of 38,868 jobs compared to business as usual case at its peak in 2011. The economy would slightly recuperate, but by 2030 it would be behind by 22,736 jobs. The total population loss would be about 51,000 people at its peak in 2013. By 2030, the region would still be short of 26,485 people. The gross regional product will drop by $3.47 billions in 2030. The maximum impact would felt by the service sector that would still be short by 9,578 jobs in 2030. The employment, population and gross regional product trends are shown in graphs below. Figure 13 provides detailed impact of the closure decision over time.

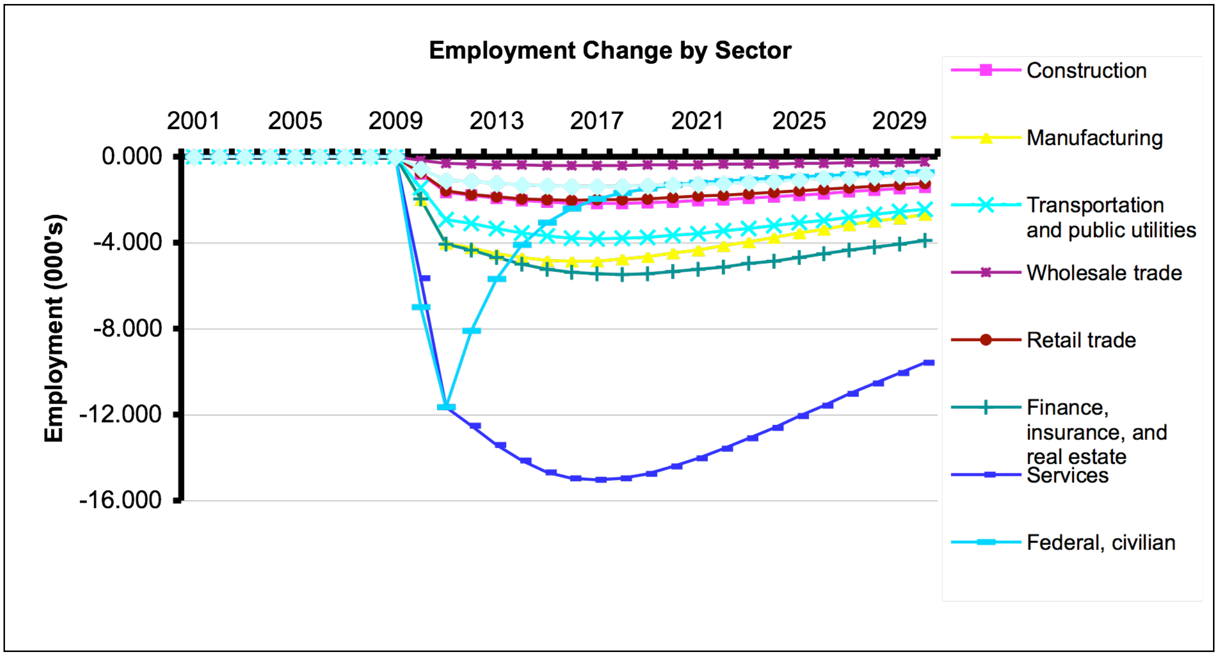


Figure 13: Employment Impacts of Potential Scott Air Force Base Closure

5.2.6 Social Driver Development (LEAMsocial)

The Land-use Evolution and impact Assessment Model (LEAM) simulates land-use change generated from new development based on projected population growth and proximity to attractors such as roads and city centers. The weighting of attractors is such that if a vacant cell exists close to city centers in the form of developable land, it has a high probability of development. However, high vacancy may signify areas that are unattractive for development due to demographic or housing conditions. The LEAM Social Model was developed to address this gap – to capture the social or demographic factors affecting patterns of migration and new development in the Scott Air Force Base (ten-county St. Louis) region. Particular emphasis has been placed on areas of exodus or abandonment, to better understand the dynamics of depopulation that occur in parts of the region.

In a May 2003 workshop, St. Louis regional stakeholders brainstormed and voted upon drivers and scenarios of land-use change. When considered in broader categories, social factors constituted 27% of drivers but only 5% of scenarios. This difference reflects at once the importance of including social drivers in an analysis of land-use change, and also the difficulty of identifying leverage opportunities therein. In addition to their importance to the region, social factors related to metropolitan development have been investigated by a number of scholars. Temkin and Rohe (1998) examine factors influencing the strength of social capital in

neighborhoods and thereby their resilience to urban ecological change. Downs (2000) investigates the relations between sprawl and decline across American cities, postulating conditions associated with poverty that may cause migration to the suburbs. Further examination is warranted within metropolitan areas, as described for the case of St. Louis below.

Although development of social theory would be helpful for addressing the social dynamics at play in metropolitan areas, a data-based approach was deemed most immediately useful to inform LEAM. Three empirical analyses were employed at with tract-level census data to examine the social factors embedded in the dynamics of land-use change in the St. Louis region: a spatial analysis of poverty rates in 1990 and 2000; a historical analysis of housing change from 1970 to 2000; and identification of development indicators to inform land-use change.

The analysis began with poverty rate to capture elements of social distress. As used here, poverty rate is the fraction of individuals with incomes below a specified threshold, based on the cost of living to meet the most basic needs. An exploratory analysis revealed the presence of poverty in high concentrations in the center city and East St. Louis areas. Analysis of spatial clustering (autocorrelation) of poverty using a variety of measures for tract neighborhood revealed substantial isolation of poverty, and an increase in this isolation from 1990 to 2000.

With the acquisition of a dataset that extended back to 1970, and using 2000 tract boundaries (as such boundaries change frequently), a thorough historical analysis examined correlates of housing and population change. Housing change (percent change during a decade relative to the base year at the start of the decade) was used as the critical dependent variable, as it ties most directly to land-use change. A variety of regression techniques were used to assess the approximate level of significance of demographic attributes in a base year on housing change in the subsequent decade. Although significance levels varied with decade and with method, certain factors surfaced as significant across the analyses.

Based on the results of the historical analysis, indicator maps were prepared for each of four factors: vacancy rate, average household income, rental rate, and proportion of residents without vehicles. To inform the land-use change drivers of LEAM, a development likelihood function was created based on the frequency of housing unit increases as they correspond with variable levels at the start of the most recent decade (1990-2000).

The spatial and temporal analysis of census data highlights first that poverty is clustered in and around the central city, while affluence is clustered around the fringes; spatial disparity between rich and poor is increasing. Figure 14 shows how clusters of poverty (red) become increasingly isolated from clusters of affluence (blue) from 1990 to 2000, indicating growing economic disparity in the region.

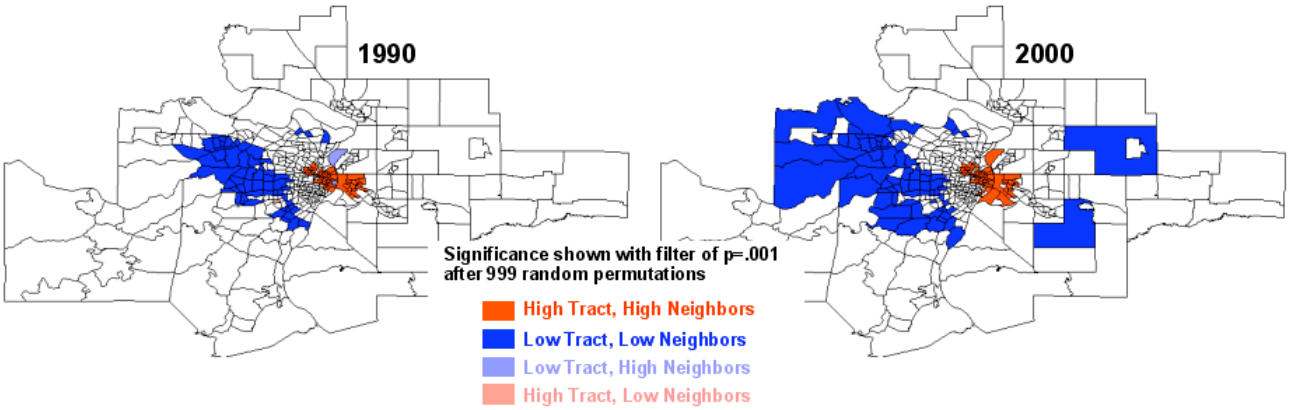


Figure 14: The spatial auto-correlation of poverty

Historical analysis of housing change reveals that significant social drivers of land-use change in the region are vacancy rate, income, rental rate, and proportion of residents without vehicles. These demographic factors will be combined with the other drivers of land-use change in LEAM.

5.2.7 Transportation Model Implementation (LEAMtrans)

Transportation as a driver for land-use change

The impact of land-use change on transportation infrastructure and vice versa, in the St Louis region is of key importance. LEAMtrans helps in assessing the changes in travel demand in the region due to growth in region, relocation of people or introduction of new roads. The impact is measured in terms of an index 'volume-to-capacity' (V/C) ratio derived from the traffic volume and capacity of the roads. As this ratio approaches a threshold value of 0.80, we assume that the road is getting congested. This congestion then further drives a change in land-use through changed attractiveness of the affected areas.

To determining the impacts of land-use change on transportation systems, LEAMtrans uses an approach similar to the conventional four-step Travel Demand Modeling approach. In this method, 'rampsheds', are utilized in lieu of 'Traffic Analysis Zones (TAZ)'. Rampsheds are areas around a chosen ramp, to which people are more likely to go than any other chosen ramp. It is developed based on travel-time friction through cells (cost-allocation method). Rampsheds, like watersheds, represent a 'draining' of vehicles onto the main highway system. These ramps form the nodes, and the roads connecting two adjacent nodes form the links in the road network. For the analysis, only US and Interstate highways in the region were chosen.

The road network is used in the pre-processing stage to obtain the routes in the road network between all pairs of origin and destination nodes. The inputs for the LEAMtrans are:

- Land-use map
- Road network
- Rampshed map
- Trip Generation rates

These maps are processed using a programming code designed to emulate the four-steps of Travel Demand Modeling and produce traffic counts for the evening (PM) peak hour on the roads. The volumes on the roads are divided with the respective traffic capacity to obtain the V/C ratio for the road. The V/C ratio thus represents the level of utilization of the road and indicates whether the road is running congested or approaching congestion or has un-congested flow. Thus an impact due to land-use change on transportation is measured.

Traffic-flows close to the design-capacity for a road cause the travel-speed on such a road to drop below the design-speed or the free-flow speed, thus, increasing the travel-time over such a road. An increase in travel-time over a road makes it less attractive for people traveling on them. People tend to choose alternative routes, which might not be the shortest path for reaching their destination. To enable perception of this change in behavior, the employment attractors for the region are changed based on the improved travel-times over the roads. These employment attractor maps are then made available for the rest of the LEAM model to generate updated land-use for the region. Thus, the impact on transportation is translated into a driver for land-use change through this mechanism. This approach enables LEAMtrans to run parallel with the LEAM model.

LEAMtrans was developed and applied to the Scott Air Force Base (St. Louis Metro) region. The road network in the analysis was limited to US highways and Interstates in the region. The analysis produced peak hour (evening) traffic on this road network.

Preliminary results from one scenario indicate, as might be expected, that the bridges (circled area near downtown St. Louis) will become heavily congested over the years. Congestion is also likely on other main arteries. Almost all of the roads outside of the St Louis city and on the Illinois side seem to have an un-congested flow in the year 2025 (see Figure 15).

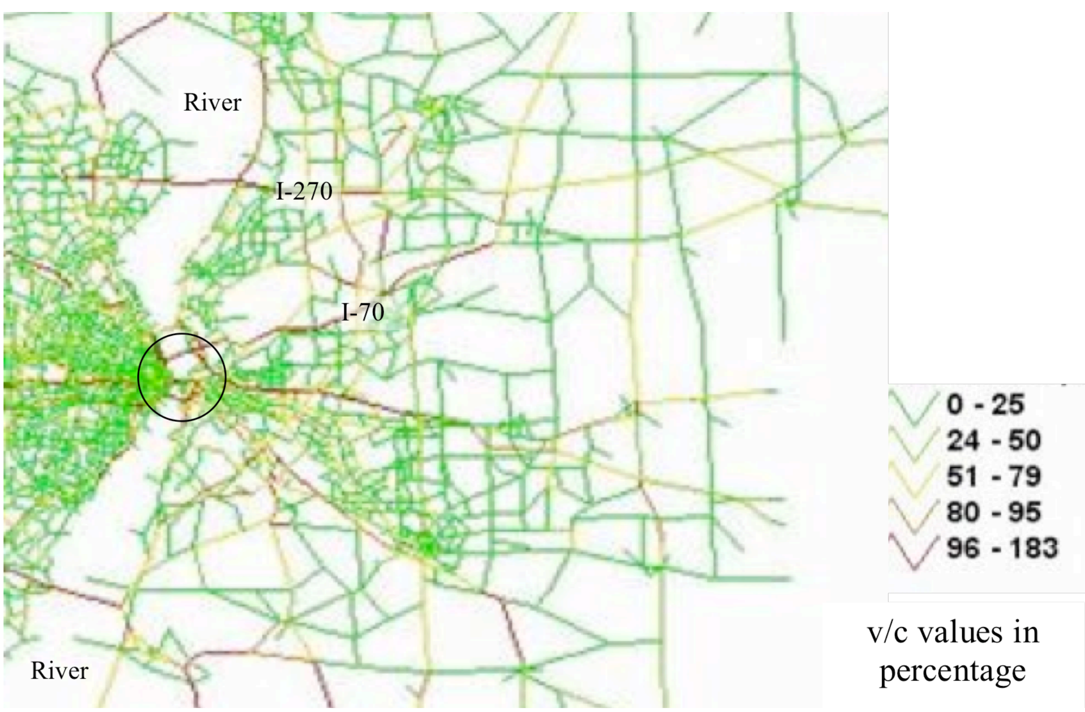


Figure 15: Projected Traffic Congestion for 2025 in the Scott Air Force Base Region

The congestion is reflected in the reduced travel-speeds and thus reduced travel-times on these roads. This reduction in travel-times causes a significant variation in the employment attractor in the region. The attractiveness of inner city areas declines while that of the outlying areas increases, thereby increasing sprawl.

Affect of Light Rail System on Land Use Change

Another key component in many urban areas (including Scott Air Force Base region) of understanding the link between transportation and land use change is the effects of a light rail system. The method developed by LEAM supposes that the ridership of a station is a proxy for the relative importance of the station with respect to the rest of the stations on the network. This implies that cells closer to multiple stations have higher attractive index than the cells that are farther away. Also the closer the cell is to a highly used station, measured by the ridership the higher the attractive index of that particular cell. Further work is underway to identify the attraction of a cell based upon the accessibility to Major destination centers (airport, downtown etc.). A sample attractor map is shown in Figure 16, the dark areas indicate the areas with the highest attractiveness for development based on this driver.

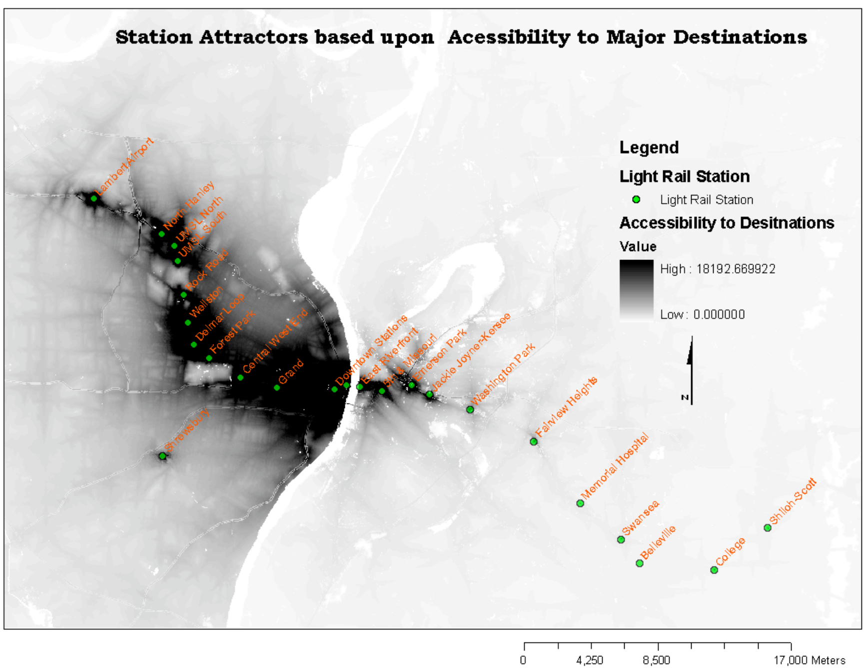


Figure 16: Attractiveness for Residential Development from Proximity to Light Rail Stations

5.3 Impact Assessments of Urban Development

With projections of future urban patterns it becomes possible to evaluate the impacts of those patterns on various sustainability aspects of the region. The LEAM analysis components and their purpose are outlined in the table below and then discussed in more detail.

LEAMtom	The training opportunities model identifies areas suitable for supporting various training and testing activities based on known or projected urban residential locations.
LEAMtrans	The transportation module that runs with LEAM to alter growth attractiveness values based on anticipated traffic congestion.

LEAMwq	A link with a water quality model to project changes in response to land use projections.
LEAMfiscal	Projects per-capita expenditures changes in response to changing settlement densities.

5.3.1 Future Training/Testing Opportunities (LEAMtom)

Traditionally, considerations of land use incompatibilities between military installations and surrounding communities has been approached with an analysis of the impact of installation activities outside the fenceline. For example, consider Figure 17. Here the left urban patterns map is combined with the results of an analysis that generated noise contours (middle image) to produce the rightmost overlay map. This map can be used to identify where residential neighborhoods and military training might be in conflict. Urban encroachment however is an insidious process that takes place over many decades in response to regional planning – the placement of roads and highways, creation of parks and open spaces, zoning and development of utilities to support residential urban development. We argued in the technical report, "Approaches for Evaluating the Impact of Urban Encroachment on Installation Training/Testing" (Westervelt, 2004a) that it is impossible and unwise to attempt to predict how an installation will be used decades into the future and therefore we do not have the input data to conduct analyses represented by Figure 17. Instead we argue for a fundamentally different approach that involved 1) predicting future urban patterns and then 2) identifying where, in those patterns, training could occur without undue complaints from the residential areas in those urban patterns.

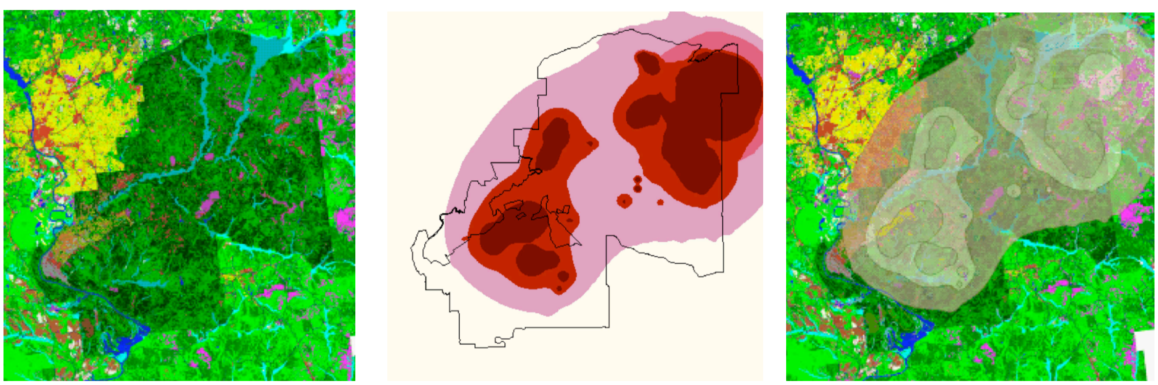


Figure 17: Projected Land use and Projected Noise Contours around Fort Benning, GA. (The town of Columbus, GA, is NW of the installation.)

Consider only one family living in an area where military training is being planned. Where, in the area could that training be located without generating complaints from this family? It is easy for any of us to acknowledge that the further away the training is, the less likely we are to complain. Consider, specifically, noise associated with training. The intensity of the training generated sound at our home decreases with distance from that training. This notion is captured in a 1-D in the left graphic in Figure 18 and in 2-D in the right graphic.

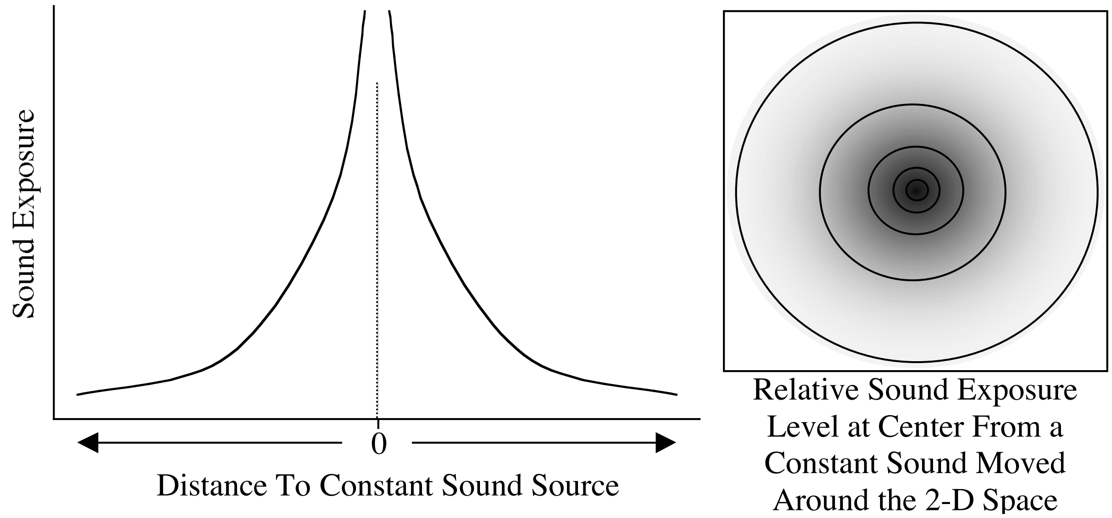


Figure 18: Noise Reception Decreases With the Square of the Distance

Now consider that there are many residential homes in the area. In this situation the probability of complaint by anyone in response to training at a particular location is the combination of the probability of complaint by each individual residence. Figure 19 is the result of such an analysis. In this image, the central areas of Fort Benning (in yellow) can support loud artillery training without generating significant probabilities of complaint by the surrounding residential areas. Training conducted in the red areas have a 100% probability that someone will complain and the rainbow gradations represent probabilities between 0 and 100% (yellow-green to purples). The installation boundary is a white line and the residential areas are indicated by white dots; the mass of dots to the northwest is Columbus, GA. Lakes and rivers are in a grey-blue. Note that areas classified as residential-urban within Fort Benning are not contributing to the probability of complaint analysis.

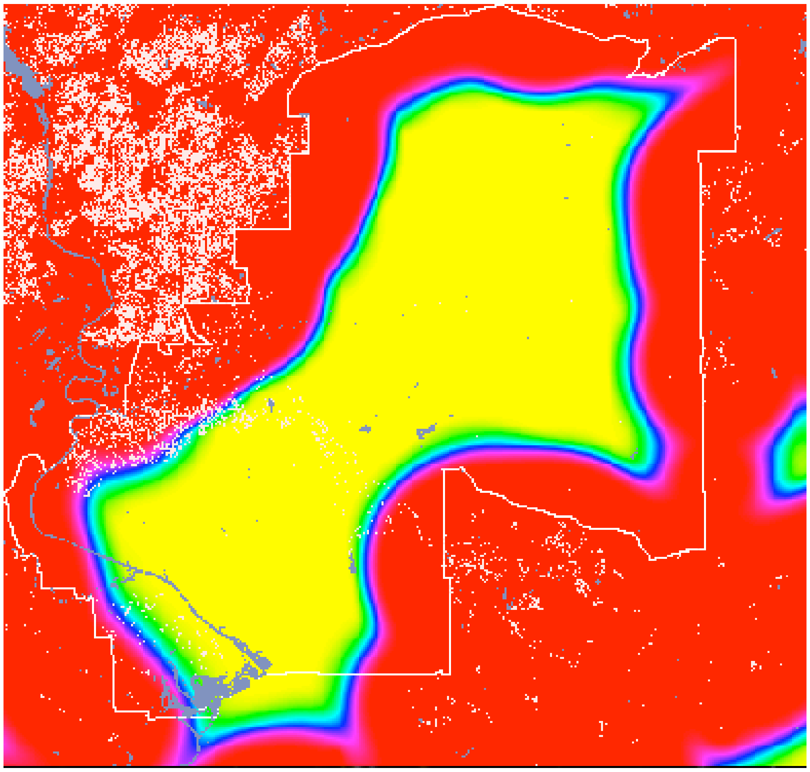


Figure 19: Sample Identification of Artillery Training Areas at Fort Benning

This approach has been adapted mathematically to convert urban patterns to identification of suitable areas for training for 1) noise generating land and air training, 2) dust generating maneuver training, and 3) radio frequency generating ground training. It has also been adapted to identify suitable night training areas.

The images in Figure 20 represent the probability of complaint associated with artillery noise in 1993 and after a projected urban growth in 2030. Note the loss of training opportunities especially along the southern, southeastern, and northeastern boundaries. Figure 21 is a similar analysis, but considers the noise associated with tracked vehicle training. As expected, the total area acceptable for tracked vehicle training is significantly larger than the area acceptable for artillery training. The most significant loss is in the potential for training in areas outside of the current installation boundary to the south and southeast.

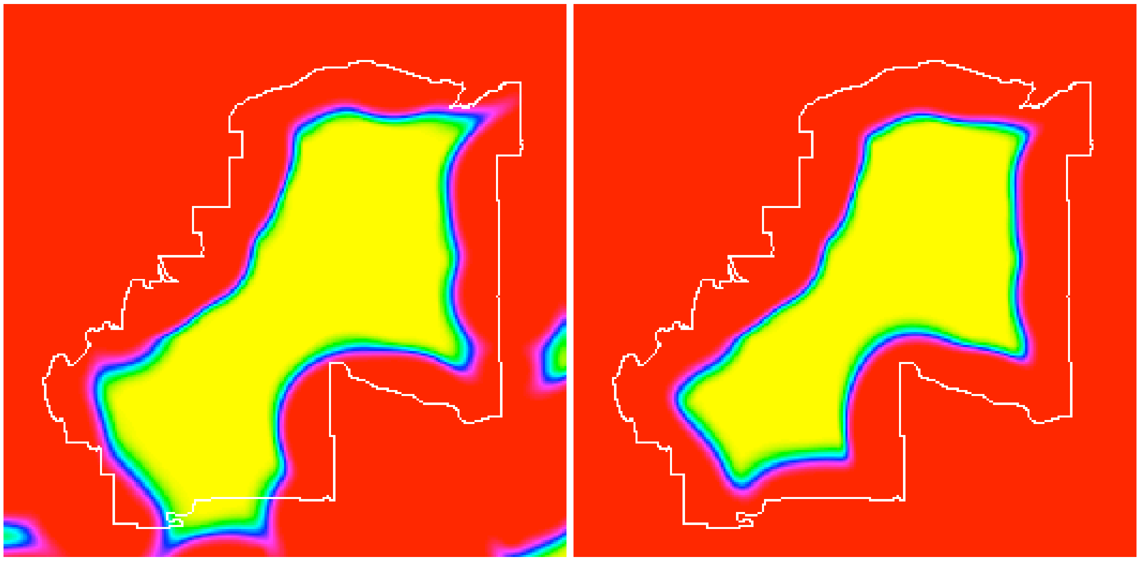


Figure 20: Change in Artillery Noise Training Opportunities 1993-2030

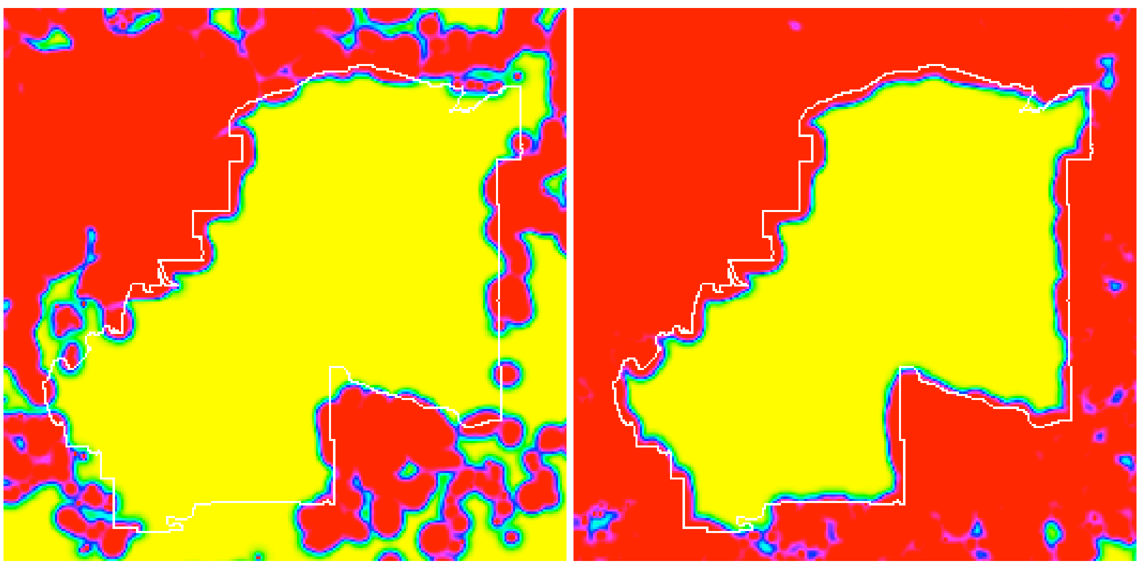


Figure 21: Change in Tracked Vehicle Noise Training Opportunities 1993-2030

An important aspect of training today involves the use of various night vision electronics, which requires a relatively dark night for effective training. With human residential and commercial development comes night lighting on homes, businesses, and vehicles. The analysis results viewed in Figure 22 show the overall loss of areas that experience very dark nights over time. The actual enlightening of the sky over an installation is based not only on light sources, but the amount of light reflected by particles and moisture in the night sky. The extremely dry air of deserts will result in darker skies around urban areas than high-humidity skies of the mid-west, southern, and eastern United States.

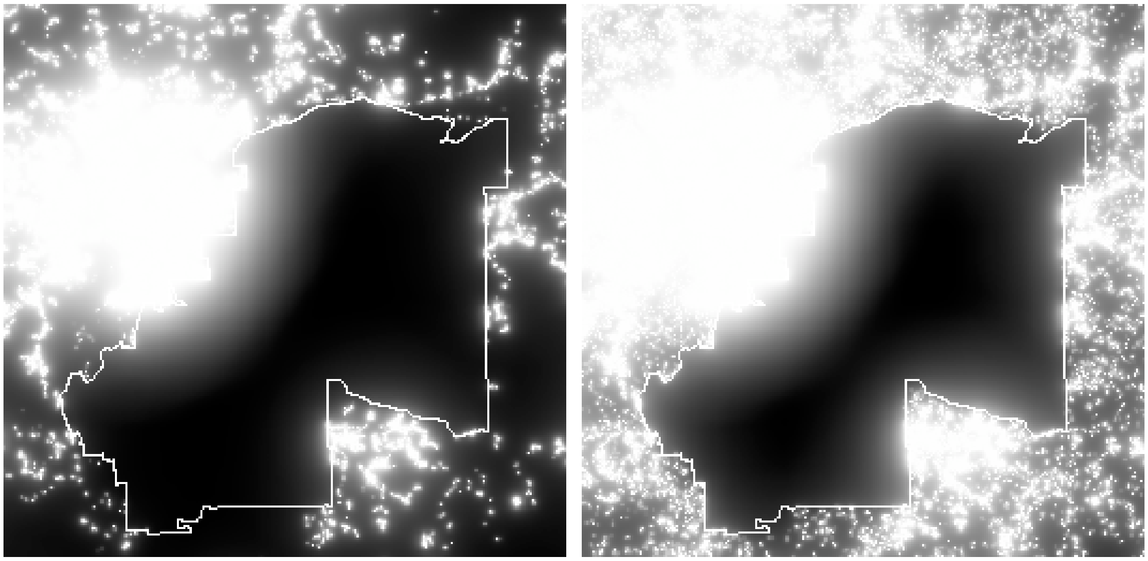


Figure 22: Change in Night Light Intensity 1993-2030

Returning to the noise theme, we modified our noise analysis programs to accommodate aircraft as represented in Figure 23 (C130 training at low altitude) and Figure 24 (F22 training at high altitude). In these images green colored areas are associated with virtually zero probability of community complaint, yellow with some probability, and red with virtually 100% probability. Note in these images the loss of C-130 opportunities off installation and the vanishing opportunities for training with F22 aircraft in a joint training exercise over time.

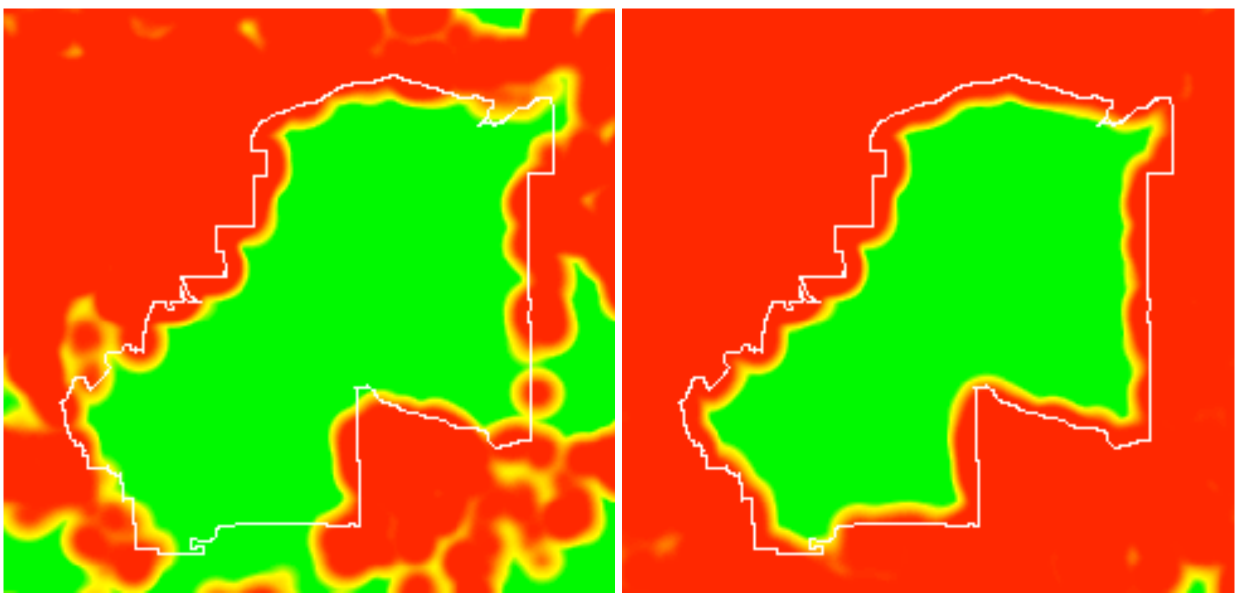


Figure 23: Change in Suitable Training for a C130 Aircraft at 2000 ft 1993-2030

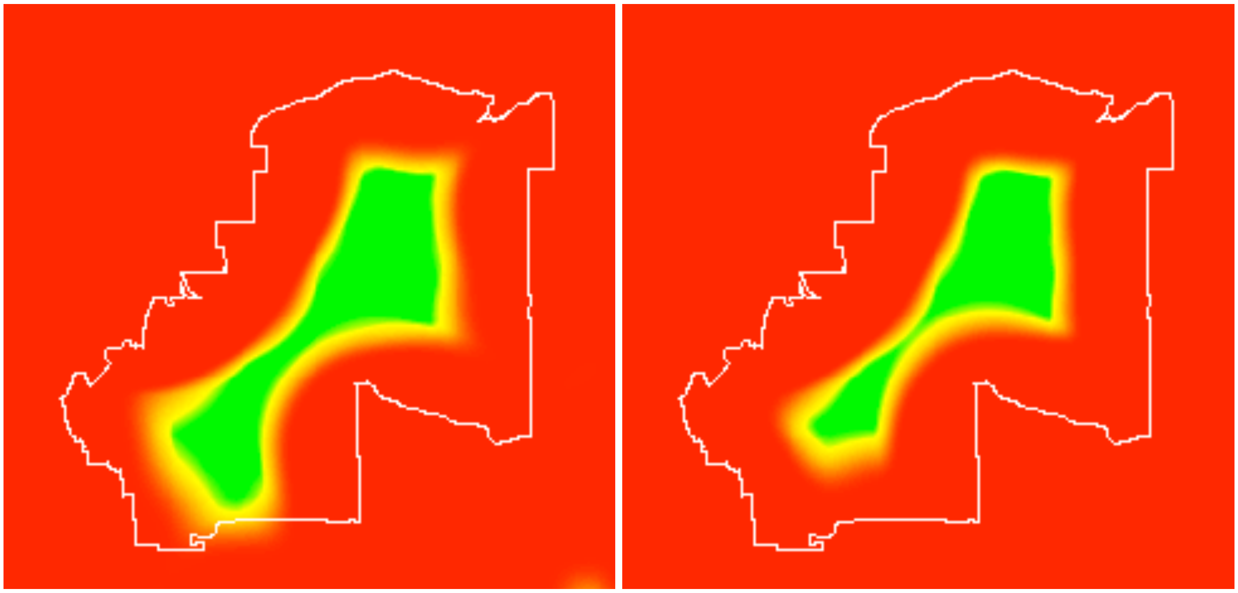


Figure 24: Change in Suitable Training for an F22 at 15000 ft. 1993-2030

Dust and smoke can be a significant source of complaints associated with military training. We developed algorithms to identify areas where dust-generating training could be accommodated within and near urban patterns. Figure 25 shows results from predicting complaint probabilities associated with a continuous dust generation in about a 4 mph breeze on Fort Benning. Urban areas off the installation are presented here in grey with overlaid highways in black. Black areas identify those locations where this dust generation scenario will result in a 100% probability of complaint, dropping off to 0% in the white areas. The algorithm supports a wide range of dust/smoke generation rates and wind speeds.

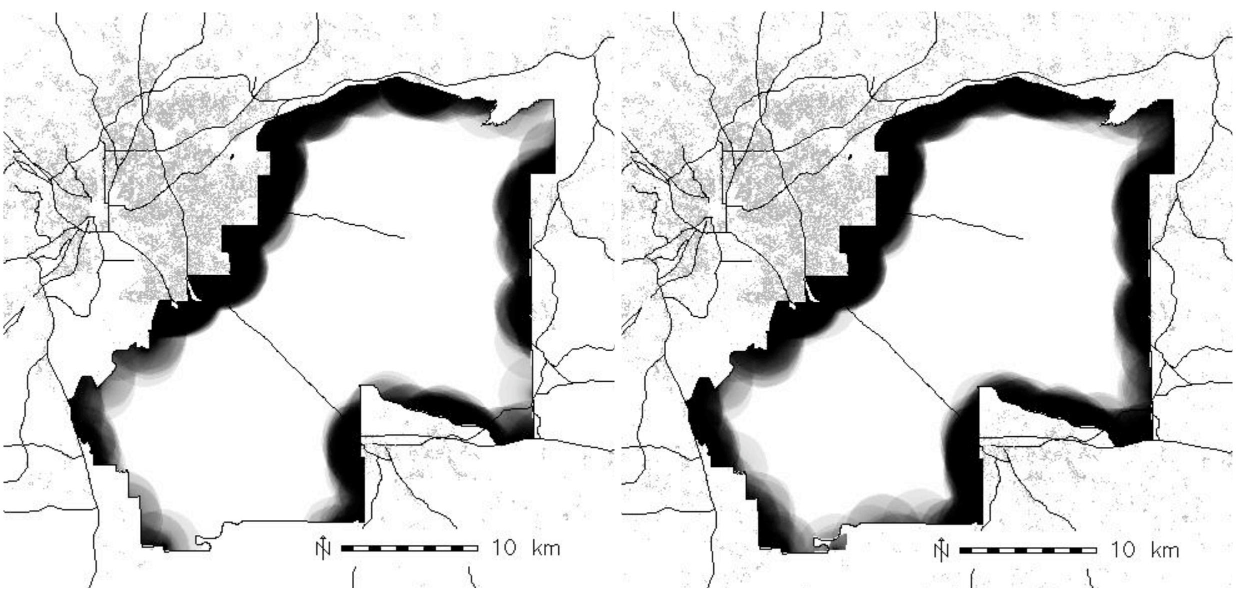


Figure 25: Change in Suitable Areas for Dust-Generating Maneuver Training 1993-2030

5.3.2 Impact Model: Traffic Volume (LEAMtrans)

LEAMtrans is a simple transportation model approach that runs in step with LEAMluc. During urban growth simulations, traffic demand is calculated for "vehicle sheds" and compared with the associated travel capacities. When capacities are reached, the attractiveness of all parcels in the vehicle shed are reduced, thereby reducing urbanization. For the St. Louis area, predictions of traffic congestion using LEAMtrans were similar to those made using the more rigorus CUBE transportation modeling program (http://www.citilabs.com/). Figure 26 illustrates the change in congested highway vehicle sheds (catchment areas for links in the highway network) from 2000 (left) to 2025 (right) as computed using LEAMtrans. Red vehicle sheds are congested, green are free of congestion. Note the increase in congested areas in 2025. At this scale, comparisons with the results from applying the CUBE model to the same land-use pattern in 2025 are very favorable.

Redder areas represent areas of increased congestion and reduced attractiveness. The congestion is reflected in the reduced travel-speeds and thus increased travel-times on these roads. This increase in travel-times, cause a significant variation in the employment attractor in the region. The attractiveness of inner city areas declines while that of the outlying areas increases, thereby increasing the possibility of sprawl.

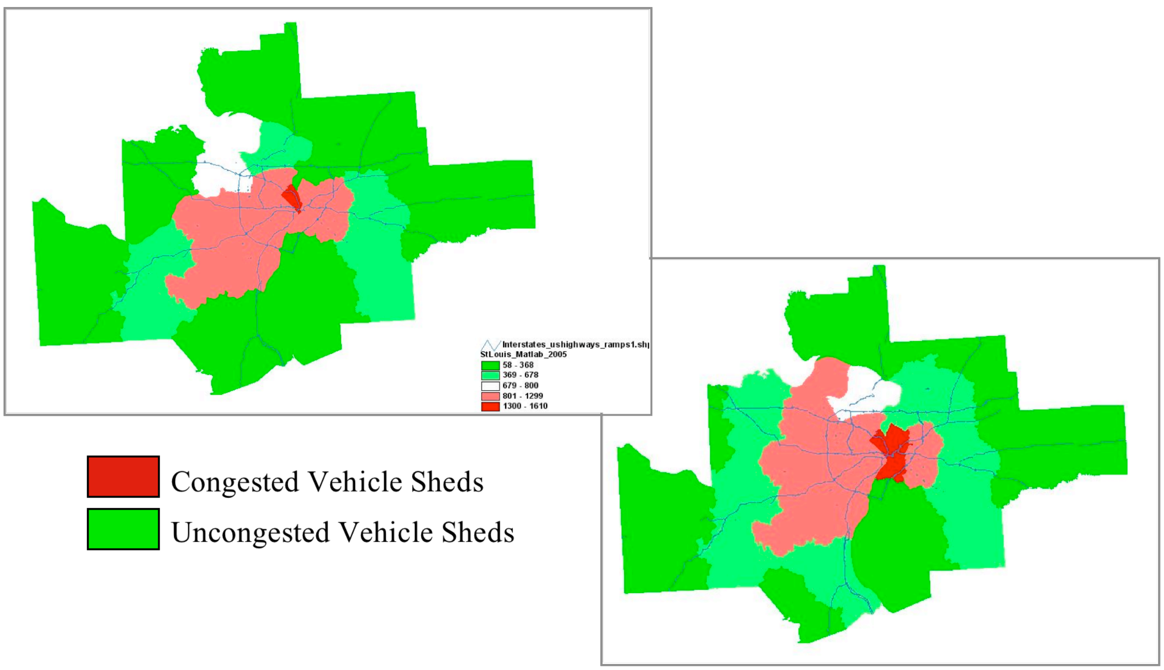


Figure 26: The change in congested and un-congested vehicle sheds in 2000 (left) and 2025 (right).

5.3.3 Water Quantity/Quality Model Development and Implementation (LEAMwq)

Hydrologic and water quality impacts can be quantified by combining a spatial urban growth model and a hydrological and water quality model. A dynamic hydrological and water quality model is capable of capturing the temporal pattern of streamflow and water quality variables such as sediment loading or nutrient concentration. This model can provide watershed planners information on how future land use change can effect flooding in the region and which

watersheds (and sub-watersheds) are facing the greatest risk to water quality for a variety of pollutants. This study shows the potential effect of future urbanization in the Richland Creek watershed in St. Clair County, Illinois (near Scott AFB). Overall, the impacts of urban growth in the region on hydrology and water quality may not be significant in terms of mean pollutant levels, but may be substantial in terms of maximum values. However, the impacts are different in different locations of the watershed due to the concentration of development in the upstream area. The future urban growth simulated by LEAM can increase the risk of flooding and lead to increased pollutant yields in selected parts of the watershed.

The new LEAMwq features integration of LEAM and HSPF (Hydrological Simulation Program – FORTRAN). HSPF is a semi-distributed dynamic hydrological and water quality model supported by the U.S. Environmental Protection Agency. It is embedded in BASINS (Better Assessment Science Integrating Point and Nonpoint Sources), which processes GIS data for HSPF. Results from this model indicate how future growth can affect stream flow, frequency of flooding, annual sediment loading, and pollutant levels such as phosphorous and nitrogen concentrations. Figure 27 indicates how future urbanization may affect flooding in this watershed. As indicators of extreme streamflow events, Q5 (95^{th} percentile) and Q1 (99^{th} percentile) daily flows were determined from the 1970-2003 flow records as 450 and 1740 ft^3/s respectively. The number of days with mean flows over those values at the outlet of the watershed was compared under current and future conditions based on the HSPF simulation over the period of 1975-1995. Q5 shows gradual increases with urban growth, from 310 days to 327 under base scenario conditions and 335 days in the high growth scenarios.

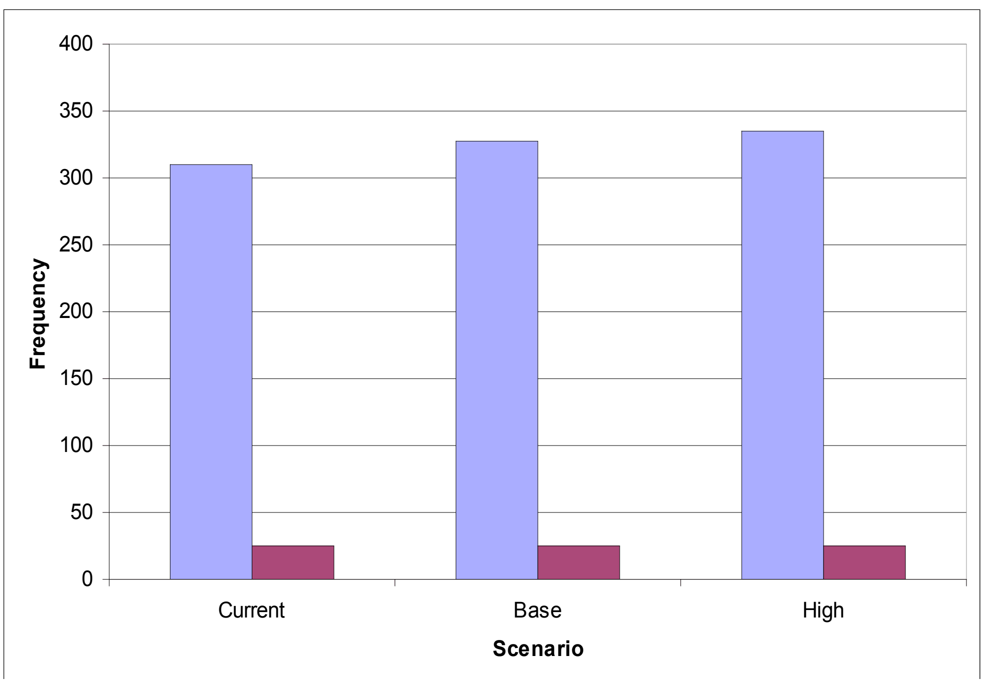


Figure 27: Frequency of Extreme Flows (Q5 light, Q1 dark)

5.3.4 Fiscal Impacts Model Development and Implementation (LEAMfiscal)

After considering various approaches already attempted by others, we tested a regression model based on per-capita expenditure in the year 2000 using a sample of 73 jurisdictions in the Illinois

portion of the Scott Air Force Base region. Our analysis suggests that there are not economies of scale: per-capita expenditure increases as the number of households increase. At the same time, jurisdictions with greater population densities have lower per-capita expenditures, and jurisdictions with greater economic activity (as measured by per-capita sales tax collection) have higher per-capita expenditures.

Table 5 illustrates the results of three scenarios for Belleville, IL (pop. 41,410). First, what if the population density were to be increased by 50% (along with a proportional decrease in land area to keep population at its present level)? Second, what if the number of households were increased by 50% (with a proportional increase in the land area to keep population density at its present level)? Third, what if per-capita sales tax were to be increased by 50% (keeping number of households and population density constant)?

Table 5: Fiscal impact scenarios for Belleville, Illinois

The results of three scenarios: population density increases 50%; households increased by 50% (with population density remaining constant); and per-capita sales taxes increased by 50% (households and population density remaining constant)?

	Change			Per-Capita Expenditure			Total
What If?	**From**	**To**		**Change**	**%**	**Amount**	**Expenditure**
50% increase in population density	848	1272	People/Sq.Km	($113)	-17.3%	$542	($6,521,868)
50% increase in number of households	17,603	26,405	Units	$27	4.1%	$682	$1,122,625
50% increase in per-capita sales tax collected	$154	$231	$/Person	$46	7.0%	$701	$1,911,900

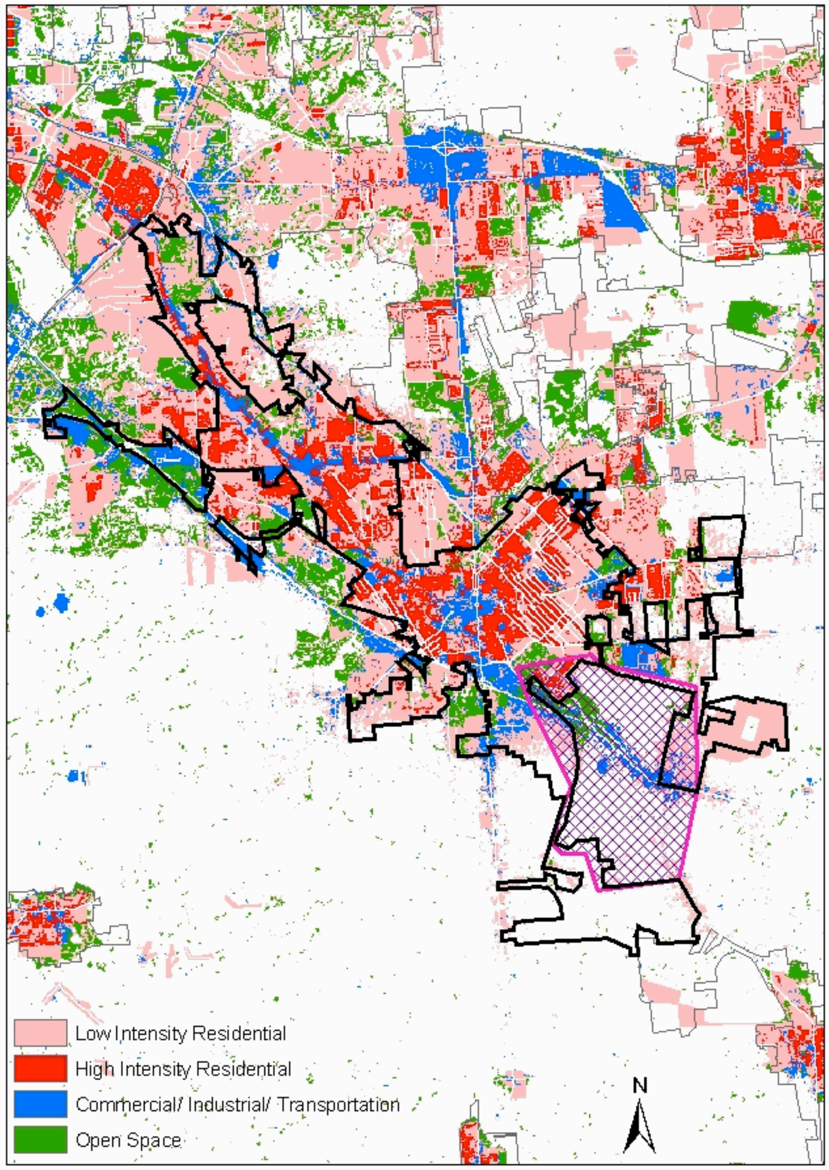


Figure 28: Potential Annexed Area of Belleville

This model was also used to assess the fiscal impact of land-use change around Belleville in a generic LEAM simulation of conditions in the year 2015. Table 4 compares two future scenarios with and without annexation to capture adjacent growth; the annexed area is indicated in Figure 28 shows Belleville's existing municipal boundary laid over land-use in the year 2015. The hatched area southwest of the city represents an area that might be annexed by the city to capture development, especially commercial growth.

Table 6: The fiscal impacts of the Belleville growth and annexation (2015) scenario

	Without Annexation	With Annexation	Difference
Population	59,861	64,963	5,102
Households	24,640	26,550	1,910
Per Capita Sales Tax	$142	$156	$14
Per Capita Expenditure	$562	$605	$43
Total Expenditure	$33,641,882	$39,302,615	$5,660,733

5.4 Model Application Tests: Scott Air Force Base and Fort Benning

The ultimate goal of this project is to predict and report alternative future land use changes adjacent to and near military installations and then evaluate those predictions with respect to subsequent limitations on training. Consequently, the final task is to select a couple of installations to be evaluated using LEAM with respect to the following questions and concerns:

- What urban growth is predicted in the region of the installation over the next thirty years in response to community generated regional planning scenarios?
- How will this growth affect the training opportunities at the installation?

Images of the current and historic land use patterns will be developed based on satellite imagery and maps. The LEAMram model was run to generate maps showing the attractiveness of land around the installations in response to the alternative local community generated regional plans. The LEAMluc model was run to simulate thirty years of growth under various potential economic conditions, economic development, public investment and other policies affecting land use in the regions to project potential future land use patterns. The predicted patterns were then evaluated by the LEAMtom analyses with respect to training opportunity indicators. Reports were then generated for each installation's analysis. Furthermore, the LEAM software will be maintained to support further applications.

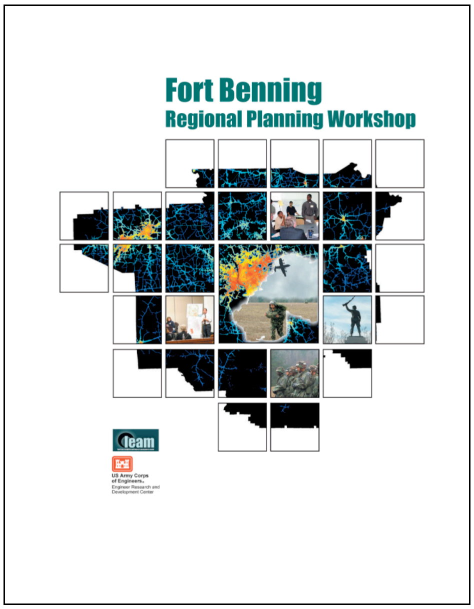
Scott Air Force Base, IL and Fort Benning, GA were chosen as sites to implement the LEAM tools and techniques to test how useful these tools are to regional and installation planning activities.

Localized applications of LEAM have been completed for Fort Benning and Scott Air Force Base regions to demonstrate the usefulness of these planning tools for enhancing local stakeholders' knowledge of the future effects of urban growth to the region and the installation. It was determined that it would be best to commence the application at both locations after the BRAC decisions were virtually finalized. The applications began with some preliminary LEAM analyses and a workshop with installation and local community representatives. Initial LEAMluc, and LEAMtom results were presented to the two communities in early November 2005. At these meetings we gathered important information to help localize the analyses, determine regional policy and public investments that the communities wanted to be evaluated in a LEAM scenario, and identify the particular long-term encroachment interests of the communities.

Scenarios that have been simulated for the Scott AFB region include expansion of Mid-America airport, a large plusup of Scott, road improvement scenarios, new industrial park areas, and limited growth in AICUZ zones. For the Fort Benning region, scenarios related to road

improvements, sewer/water facility expansion, economic development (industrial park, marina, museum), stream buffer protection, and ACUB growth restriction areas were run. LEAMtom was run on each of these scenarios to assess how training opportunities will be affected by growth under various futures. Final analyses, presentations, and reports were completed in January and March at these two sites. This full application of LEAM to these installations was completed in approximately 6 months.

We have continued to work with these installations since the final analyses were presented as planning activities continue in the area. Both installations are planning to conduct a joint land use study (JLUS) in the coming year, and the application of LEAM has provided a jump start for these studies.



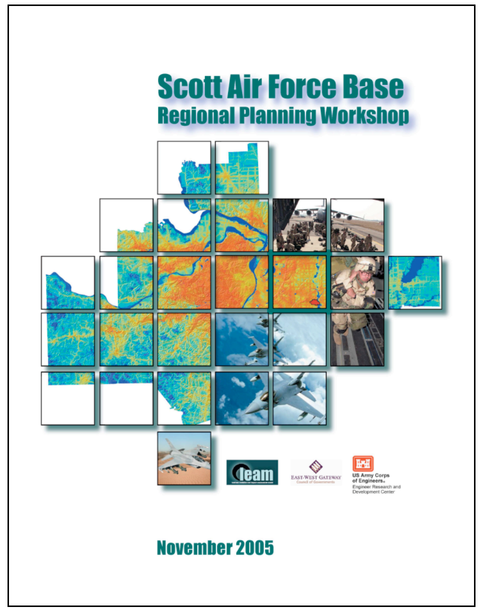


Figure 29: Pre-charette Reports

The purpose of this report was to provide key background information on the region to: (1) provide a sense of where the region is now, in terms of population and urbanization in the past, (2) provide preliminary results from LEAM to begin developing an understanding of where the region is headed, (3) provide preliminary analysis from the training opportunities model, and (4) list the information needed from stakeholders to localize LEAM

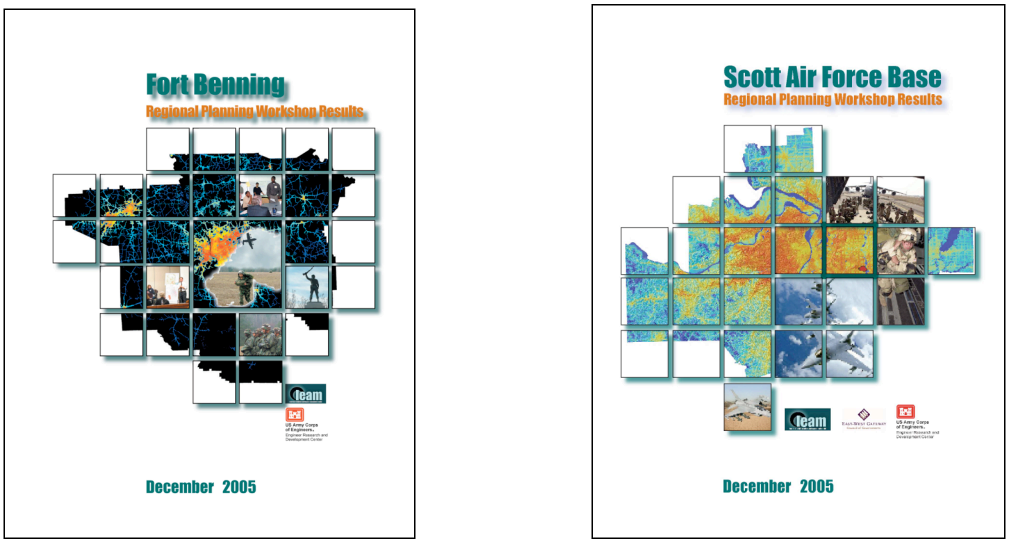


Figure 30: Workshop Results Reports

These reports provide the results of the local stakeholders' input on drivers of growth in the region, encroachment issues facing the base, and future scenarios they would like to have simulated in LEAM. Stakeholders also voted on each of these issues so that issues and scenarios can be prioritized From this information, we are able to determine what other drivers need to be included in the final localized model and select a set of scenarios to run.

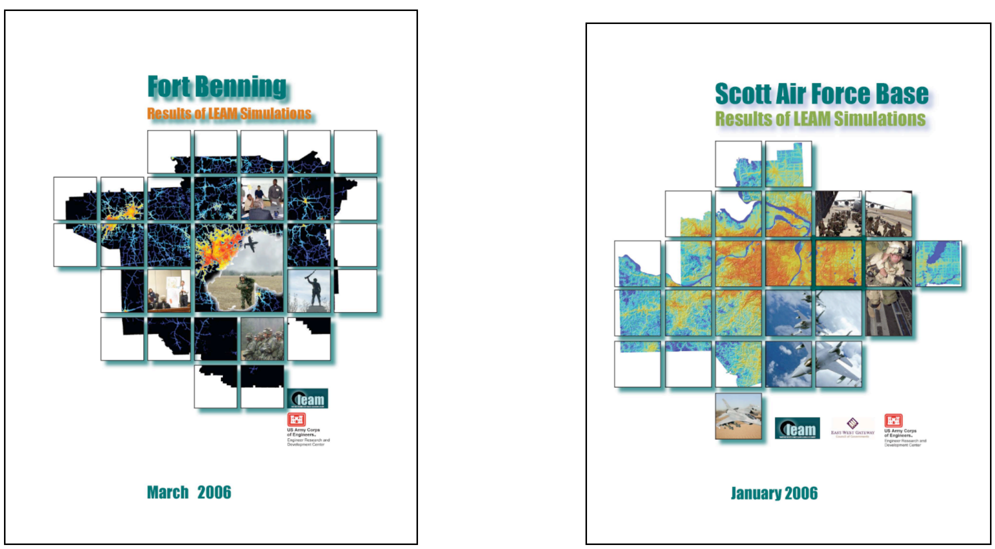


Figure 31: Final LEAM Simulation Results

Based on the input from local stakeholders in terms of localizing the model and suggested scenario, a final set of LEAM simulations were completed. The results were presented in these reports, showing how land use patterns change under various scenarios and how this may affect future military training opportunities.

The final reports are available in the appendix to this report.

5.5 Model Suite Product Summary

This project has lead to the development or enhancements of several models to improve our understanding of the current encroachment challenges associated at military installations and project future challenges installations may face from future urban development. The following table provides a summary of the software products completed.

SIRRA Sustainable Installation Regional Resource Analysis	A Web-based interface to many regional sustainability indicators (economic, ecologic, social) for all major DoD installations. Indicators are presented in mapped and tabular formats.
LEAM Land use Evolution Assessment Model	A suite of models and modeling approaches used to predict the direct and indirect impacts of proposed regional plans on future installation sustainability and encroachment factors.
LEAMluc LEAM land use change model	The core LEAM land use change model. Using a one-year time step, a calibrated LEAMluc model generates future conversions of undeveloped land to urban residential, commercial, and open space (parks).
LEAMram LEAM residential attractiveness model	A quick and dirty analysis of the attractiveness of land to future residential development with output in map form. Used to rapidly compare alternative regional plans.
LEAMecon LEAM economic model	An economic input-output and regression model that projects future population and employment based on migration of businesses (e.g. BRAC decisions) or other changes in the economy.
LEAMtom LEAM training opportunities model	GIS based analyses that interpret historic, current, and projected urban patterns with respect to probabilities of community complaint in response to military training/testing.
LEAMfrag LEAM habitat fragmentation analysis	A GIS based analysis of the fragmentation of LEAMluc generated landscapes based on the specific behavioral traits of a specific species.
LEAMtran LEAM transportation model	A road and highway traffic congestion analysis based on LEAMluc land use patterns.
LEAMfiscal LEAM Fiscal Impact Model	A STELLA model was examining how future development will affect local government's revenues and expenditures.
LEAMsocial LEAM Social Model	A model that captures how social and demographic factors affect migration and new development patterns.

6 Conclusions

The publication and software products generated by this project can be grouped into three sets: SIRRA, mLEAM, and LEAM. The utility, economic feasibility, and general attractiveness of each suite of technologies are discussed below.

6.1 Identification of At Risk Facilities

SIRRA is valuable tool incorporating 1) an extensive national database that compiles mapped sustainability indices from many nationally available sources (most of which are Federal), and 2) a generally available Internet-available interface. Using SIRRA, installation planners, Joint Land Use Studies, DoD HQ offices, Congress, and individuals can quickly view a picture of regions surrounding installations from the standpoint of 54 indicies grouped into 10 sustainability categories. With no training a SIRRA website visitor can retrieve a table of information and a variety of maps in minutes. Because all data was prepared at a national scale for general use, SIRRA is virtually free of any stakeholder interests or influence. Results for installation regions are directly comparable. Interpretation of the data is left primarily to the user, which has the advantage of SIRRA providing essentially factual information to planners.

The SIRRA capabilities are available through the SIRRA website (https://ff.cecer.army.mil/ff/sirra.do). This interface provides free access to reports and maps for various sets of DoD installations and for individual installations. Future maintenance of the website will be required and will involve data updates and delivery of new products. Organizations within and outside of DoD have begun funding this maintenance. Secondly, the ERDC-CERL SIRRA is available to access and provide further analysis of the SIRRA data and report results in ways not available through the website. Finally, the database itself can be shared to allow others the opportunity to directly analyze the data. For SIRRA to remain viable in the future, funding mechanisms must be developed to update and maintain software and data.

6.2 Spatially Explicit Urban Growth Model

6.2.1 mLEAM

The mLEAM suite of software includes LEAMram, LEAMluc, and LEAMtom. Together they allow rapid and very inexpensive analyses of any location within the United States in one to four days using freely available national data sets accessed through the Internet. The results of the analyses are automatically posted at a website (http://earth.cecer.army.mil/FF) in the form of maps and movies for end-user access. In consultation with end-users, local data sets and local regional plans encompassing changes to transportation and opportunities for development can be identified. The local data can be captured into the mLEAM analyses, which are then used to compare the long-term implications of proposed regional plans on future training and testing opportunities for the installation. The attractiveness to mLEAM lies in its very low cost and quick turnaround.

The mLEAM software is available to anyone interested in running its capabilities locally. This software requires a computer running a version of Unix (e.g. Linux) and the GRASS geographic information system. The GRASS installation must include source code as new GRASS programs that are part of mLEAM will need to be compiled. With this environment, the

mLEAM software can be installed and run. As of this writing, software installation is not automatic and will require assistance from the mLEAM developers, but should not take more than a day.

The primary purpose of mLEAM is to provide a quick and inexpensive approach for predicting urban residential development around military installations and to identify changes in resulting military training and testing opportunities. mLEAM is designed to efficiently use free nationally available data sets to allow for rapid and consistent analyses. Local data can be used to improve the analyses, and locally generated regional planning scenarios can be developed and quickly tested.

6.2.2 LEAM

LEAM is an innovative and complex suite of tools for projecting future land use patterns and examining the implications of this change. One of the major benefits of LEAM is that a region-specific model is developed for each region and the particular encroachment concerns and drivers to urban development, leading to a model that accurately reflects the land use patterns of the region and can address the specific urban growth issues facing a region. Consequently, development of a region-specific model often requires new components (drivers & impact models) to be created. However, the model can be developed for a specific region by the LEAM lab in a relatively short timeframe, depending on the size of the region and the complexity of the questions local stakeholders want answered. Local stakeholders also play a key role in developing a region-specific model, providing their insights on the region and feedback on initial LEAM simulations.

LEAM is as much about process as it is about the model. Much is learned about the region in the process of developing the model, and local stakeholders get the opportunity to share their views on regional issues with other stakeholders from various interest groups. An important step in the development of a localized LEAM model involves a charrette with local stakeholders. Its purpose is to present the generic LEAM results and have local stakeholders help assess what's wrong and right with an initial generic model, and provide local insights and identify other data that help explain urban growth patterns in the region. Local stakeholders also provide ideas in terms of what investments and policies to consider as future scenarios and what are the critical impacts that need be analyzed. Development of a generic model for a region (depending on the size of the region) and conducting a charrette takes approximately 2-3 months to complete.

Once the generic model has been reviewed and feedback has been provided, full implementation of LEAM ("localizing" the model for a specific region) begins. This entails collecting local data and development of local drivers including an economic model, employment attractors, more updating road attractors with local road network data, and other drivers suggested by local stakeholders (sometimes these have to be developed from scratch). Once these drivers have been developed and implemented in a baseline (or business as usual) scenario, simulations for other scenarios are developed. This typically involves recalculating all the drivers assuming a major investment or policy change (e.g., new road or interchange, new major employer, zoning policy) occurs. For scenarios involving major investments, updating the drivers may also require running the economic model to estimate how a specific investment may affect employment and population in the region. Once scenarios have been completed, maps and graphics are created to illustrate where and when land use change occurs, as well as population and household change. This information can be calculated for any geographical unit of interest such as counties,

townships, school districts, watersheds, and census blocks. This process of "localizing" LEAM and simulating a set of scenarios takes between 3-4 months.

It takes between 6-9 months to fully implement LEAM for a new location. The cost of transferring a given localized LEAM model to another military installation depends on the size of the defined region and the questions and issues the region wants to examine. To provide a sense of the cost of applying LEAM to another military installations, the cost of implementing LEAM to a five county region (approx 2500 sq. miles), including the steps of localizing the model, simulating 5-10 scenarios, implementing some limited number of impact models (LEAMtom and one other impact model), stakeholder engagement and final report and presentation, would be approximately $150,000.

6.3 Analysis Opportunities for Installations

The information below is being provided in brochure form as a short summary to installations interested in the analysis capabilities developed by this SERDP project.

6.3.1 My Installation's Regional Sustainability Indices

Purpose: Query 50+ national mapped data sets to identify the main challenges to installation sustainability. Useful for informing NEPA processes, joint land use studies, long-term installation planning, and installation sustainability objectives.

Cost: Free
Web site access is free. Contributions to maintain the site are welcomed.

Approach: Visit the SIRRA web site and query the available data.

Contact:
Elisabeth Jenicek, ERDC-CERL, Army Corps
217 373-7238
Elisabeth.M.Jenicek@erdc.usace.army.mil

6.3.2 Quick Look at My Region's Residential Growth

Purpose: Receive a quick-turnaround view of
- Forecasted multi-decade residential growth patterns
- Forecasted impact of those patterns on future on/off installation training/testing opportunities.

Optionally, regional planning scenarios can be compared.

Cost: $10-$15K

Time: One week

Approach: You begin by identifying your area of interest by selecting a set of contiguous counties. These are communicated to the ERDC-CERL mLEAM team, which processes your request.

Products:

Images showing residential growth and resulting acceptable training/testing areas.

Results are viewable at a Web-site. See, for example, http://earth.cecer.army.mil/FF

Contact:
Jim Westervelt, ERDC-CERL, Army Corps
217 373-4530
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6.3.3 Detailed Analysis of My Region's Urban Growth

Purpose: Detailed analysis and forecast of local urban growth patterns in close collaboration with local stakeholders. Participants from the local region provide local GIS maps and alternative regional planning scenarios. These are analyzed to forecast future urban patterns and their direct and indirect impacts on future military training/testing opportunities.

Cost: $150K-$300K

Time:

Approach: The analysis beings with the "quick look" described above. A planning charrette is scheduled to include local regional planning stakeholders. Results of the quick analysis and the approach to the project are presented. Participants identify how the model can be improved and identify regional planning scenarios to be tested. This information is used to develop, calibrate, and test a localized urban growth model for the area, which projects future development of residential, commercial, and urban open space. Results are presented in a final meeting.

Products: A variety of products can be provided

- "Quick look" results
  - Posted to open website for community review
  - Public report
  - Presentation at a community charrette
- Charrette
  - Presentation of the entire effort – goals, approaches, products
  - Discussion of "quick look" results
  - Discussion of growth drivers, development concerns, and local data sources
  - Identification of regional planning scenarios considered by the community
  - Public post-charrette report of findings
- Projected economic and population growth
  - Regional multi-sector economic input-output model developed with regional data
  - Project economic and population growth based on significant project changes (e.g. military buildup)
- Localized LEAM land use change model
  - Adapt local data
  - Modify generic LEAM urban growth model to capture local growth drivers
  - Calibrate using historic data
- Analysis of proposed regional planning scenarios
  - Forecast of future urban patterns (30-50 years)
  - Identification of suitable training areas that remain …
    considering dust, smoke, night lights, and noise
- Final results
  - Documented in a final report
  - Presented to the local communities

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6.4 Summary

Several innovative planning tools have been developed and/or upgraded as a result of this project that can assist planners in understanding the implications of urban growth occurring near military installations and develop strategies for securing the long-term viability of installations.

The Sustainable Installation Regional Resource Assessment (SIRRA) tool was completed and released in July 2004. The database includes 48 sustainability indicators for 309 military installations. This tool has attracted significant outside interest and funding because of its usefulness for the latest Base Realignment and Closure (BRAC) efforts. SIRRA was upgraded in FY05, as a result of other funding, to allow different agencies to update different components of the database. SIRRA has been established as a stand-alone web site at ERDC (https://ff.cecer.army.mil/ff/sirra.do) and the SIRRA methodology has been adapted for watersheds rather than installations.

Another innovative tool resulting from this project is the suite of LEAM products that were developed or enhanced. The focus of development of this tool for the first three years of the project focused on the refinement and upgrade of LEAMluc and the development of a variety of submodels to address environmental, social, and economic issues. Driver and impact submodels were developed to address economic impacts, transportation systems(roads and light rail), fiscal impacts, water quality/quantity, habitat fragmentation, and a social driver model. The final year of the SERDP project focused on the development of the military training and testing opportunities models (LEAMtom) and the application of the LEAM suite of tools to two installations. The training opportunities model uses urban pattern projections from LEAM to identify where training/testing is suitable; areas where training can occur without significant complaints from residential areas from noise, dust/smoke, radio frequencies, and light pollution. While the focus in this last year of the project has moved away from further development of LEAM to the training opportunities modeling, new development and refinement of LEAM have continued as a result of funding from other projects. Furthermore, LEAMram, the quick and dirty land use change model, has been applied to about twenty installations and other regions.

After development of this suite of LEAM products was complete, LEAM and the training opportunities model were applied to two military installations– Scott Air Force Base, Il and Fort Benning, GA - to illustrate how this tool can help the installation and surrounding communities to identify potential encroachment issues and other issues that may arise from future urban growth. This process involved meetings with local stakeholders (installation staff and local community representatives) to obtain information on what drives growth in the region, a critique

of initial LEAM simulations, and suggestions on "what-if?" scenarios they were interested in. This information was used to "localize" the model, so that the model more accurately reflected the current state of the region and improved future growth pattern results. In each application of LEAM, we completed several key scenarios identified by stakeholders and presented results to local stakeholders including projected growth patterns and their potential impact on military training opportunities. The local stakeholders found the information from this project to be valuable in terms of understanding future encroachment issues. Both installations are planning to do a Joint Land Use Study (program managed by DOD Office of Economic Adjustment) in the coming years and found that the preliminary tools and analysis from these LEAM applications should be useful in the formal study process.

Consequently, this project has lead to the development of many useful and innovative planning tools that installation personnel and local communities can use to better understand the issues facing military installations in the future and, hopefully, help ensure the long-term sustainability of installations.

The SERDP website is at http://www.serdp.org. The specific project, under which this work is being conducted, is CS-1257, under Conservation, Ecological Forecasting, entitled: *The Evolving Urban Community and Military Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities*.

6.5 References

Acevedo, W. and Masuoka, P., 1997. Time-series animation techniques for visualizing urban growth. Computers & Geosciences, 23: p. 423-35.

Allen, P., Deneubourg, J.L., Sanglier, M. and DePalma, A., 1978. The Dynamics of Urban Evolution. Final Report to the US Department of Transportation.

Batty, M., 1992. Urban Modeling in Computer-Graphic and Geographic Information System Environments. Environment and Planning, 19: p. 678-708.

Birkin, M., 1990. Elements of a Model Based Geographic Information Systems for the Evaluation of Urban Policy. In: L. Worrall (Editor), Geographic Information Systems. Belhaven Press, London.

Clarke, K.C., Hoppen, S. and Gaydos, L., 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B: Planning and Design, vol. 24: p. 247-261.

Deal, B., 2001. Ecological Urban Dynamics: the Convergence Spatial Modeling and Sustainability. The Journal of Building Research and Information.

Deal, B., Farello, C., Lancaster, M., Kompare, T. and Hannon, B., 2000. A Dynamic Model of the Spatial Spread of an Infectious Disease: The Case of Fox Rabies in Illinois. Environment Modeling and Assessment, V. 5: p. 47-62.

Deal, B., Goran, W. and Timlin, D., 2001. Evolving Urban Dynamic and Military Installations: The Quest to Co-Exist. Federal Facilities Environmental Journal.

Deal, B., Goran, W. and Timlin, D., 2001. A Spatial Modeling Approach to Address Urban Growth Threat to Military Training. Joint Forces Quarterly.

Deal, B. and Hannon, B., 2001. An Ecological Approach to Modeling Urban Environments using Cellular Automata; the Mill Creek Watershed Model. The Journal of Ecological Economics.

Dendrinos, D.S., 1979. A Basic Model of Urban Dynamics Expressed as a Set of Volterra-Lotka Equations. US Department of Transportation, Washington, D.C.

Downs, Anthony. 2000. "Relating Sprawl to Urban Decline: Effects of Suburban Sprawl on the Decline of Metropolitan Areas." Chapter 13 of *Costs of Sprawl – 2000*. Transportation Cooperative Research Project (TCRP) Report 74. Washington, DC: National Academy Press. pp. 373-439. http://trb.org/publications/tcrp/tcrp_rpt_74-c.pdf

EPA 2000. Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns

EPRI 1999. EPRI, Electric Power Research Institute.

Forrester, J.W., 1970. Urban Dynamics. M.I.T. Press, Cambridge, Mass.

Goran, W.D., Deal, B., Aden, T. and Timlin, D., 2000. Urban Growth: A Challenge to Sustaining U.S. Department of Defense Land Uses. In: D.J. Brunckhorst (Editor), Bioregional Planning: Resources Management Beyond the New Millennium. Harwood Academic, Amsterdam.

Hannon, B. and Ruth, M., 1994. *Dynamic Modeling*. Springer-Verlag, New York, NY.

Hannon, B. and Ruth, M., 1997. *Modeling Dynamic Biological Systems*. Springer-Verlag, New York, NY.

Klosterman R E, 2001, ``TheWhat if? planning support system", in *Planning Support Systems: Integrating Geographic Information Systems, Models and Visualization Tools*, Eds R K Brail, R E Klosterman (ESRI Press, Redlands, CA) pp 263 ^ 284

Klosterman, R.E., 1994. Large Scale Urban Models: Retrospect and Prospect. Journal of the American Planning Association, 1.

Landis, John; Reilly, Michael; Twiss, Robert; Foster, Howard and Frontiera, Patricia, 2001, *Forecasting & Mitigating Future Urban Encroachment Adjacent to California Military Installations: A Spatial Approach*, University of California, Berkeley, WP-2001-11, 101pp.

Lee, D., 1973. A Requiem for Large-Scale Models. *Journal of the American Planning Association*.

Maxwell, T., Villa, F. and Costanza, R., 1999. *The Spatial Modeling Environment (SME).* International Institute for Ecological Economics, Center for Environmental Science, University of Maryland System, Solomons, MD.

Risser, P.G., J.R. Karr, and R.T.T. Forman. 1984. *Landscape ecology: Directions and Approaches*. Special Publication No. 2. Illinois Natural History Survey, Champaign, III.

Temkin, Kenneth and William M. Rohe. 1998. "Social Capital and Neighborhood Stability: An Empirical Investigation." *Housing Policy Debate* 9(1): 61-88. http://www.fanniemaefoundation.org/programs/hpd/pdf/hpd_0901.pdf

Westervelt, J.D., Hannon, B.M., Levi, S. and Harper, S.J., 1997. *A Dynamic Simulation Model of the Desert Tortoise (Gopherus agassizii) Habitat in the Central Mojave Desert. U.S. Army*, Corps of Engineers, CERL, Champaign, IL.

Westervelt, J.D., Hannon, B.M., Sheikh, P., Cheng, A., Rubin, C., Dvorak, B., Nugtern, A., Gildensoph, L., Mitasova, H., Lambert, E., Iverson, L., Pabich, K. and Shapiro, M.R.N., 1995. *Dynamic, Spatial, Ecological Modeling: A Demonstrated Simulation of the Sage Grouse Habitat at the Yakima Training Center*. U.S. Army, Corps of Engineers, CERL, Champaign, IL.

White, R. and Engelen, G., 1997. The use of constrained cellular automata for high-resolution modeling of urban land-use dynamics. *Environment and Planning B: Planning and Design*, vol. 24: p. 323-343.

Wilson, A.G., 1981. *Catastrophe Theory and Bifurcation: Application to Urban and Regional Systems*. Croom Helm, London.

7 Appendices

7.1 List of Technical Publications

7.1.1 Journal Articles

Aurambout, J.-P., A. G. Endress, Deal, B.M. (2005). A spatial model to estimate habitat fragmentation and its consequences on long-term persistence of animal populations. *Environmental Monitoring and Assessment*, Volume 109, Numbers 1-3, pp. 199-225.

Choi, W. and B. Deal (In progress). Dynamic Hydrological Modeling Using HSPF Under Future Urban Growth, *Environmental Modeling & Assessment*

Wang Y., W. Choi, and B. Deal (2005). Long-Term Impacts of Land-Use Change on Non-Point Source Pollutant Loads for the St. Louis Metropolitan Area, USA, *Environmental Modeling & Assessment,* Vol 35 No. 2, pp 194-205

Deal, Brian, D. Schunk. 2004. Spatial Dynamic Modeling and Urban Land Use Transformation: A Simulation Approach to Assessing the Costs of Urban Sprawl. *The Journal of Ecological Economics*. Volume 51:1-2, 79-95

Deal, Brian, Z. Sun. 2006. A Spatially Explicit Urban Simulation Model: The Land-use Evolution and impact Assessment Model (LEAM). published in: *Smart Growth and Climate Change*. Ruth, M (ed). Springer, New York

Eastgate, C. J. and D. A. Morrison, (submitted) Exploring impact indicators for military and urban land use incompatibilities, *Journal of Military Operations Research*.

Ginsberg, M. D. (submitted) Frequency encroachment on military installations, *Journal of Military Operations Research*.

Ginsberg, M. D. (submitted) Light pollution encroachment on military installations, *Journal of Military Operations Research*.

Goran, William and Brian M. Deal. 2002. Technologies to Help Installations Plan Across Fence Lines. *Army Acquisition, Logistics, and Technology*, 2002, 32-34.

Kemme, M. and J. Westervelt, (submitted) Military Unique Particulate Matter Emissions and Urban Encroachment, *Journal of Military Operations Research*.

Sun, Zhanli, Brian Deal, V. Pallathucheril. (in review). The Land-use Evolution and Impact Assessment Model: A Comprehensive Urban Planning Support System. *The Journal of Urban and Regional Information Systems*. (http://www.urisa.org/publications/journal/articles/the_land_use_evolution)

Wang, Y., W. Choi and B.M. Deal, 2005. Long-term Impacts of Land Use Change on Non-point Source Pollutant Loads for the St. Louis Metropolitan Area, USA, *Environmental Management,* 35:2, p 194-205

Westervelt, J and M. White, (submitted) Identifying future military land use opportunities, *Journal of Military Operations Research*.

Yang, Limin, G. Xian, J. Klaver, and Brian M. Deal. 2003. Urban Land Cover Change Detection Through Sub-Pixel Imperviousness Mapping Using Remotely Sensed Data. *Photogrammetric Engineering & Remote Sensing* 69, no. 9:1003-1010.

7.1.2 Technical Reports

Deal, Brian M. *The Military Land use Evolution and impact Assessment Model (mLEAM).* Technical Note TN-01-2. 2001. Champaign, IL, Engineer Research and Development Center [CERL].

Deal, Brian M., D. Timlin, and William Goran. *Urban Encroachment of Military lands: Military Installations at Risk.* TR-02-3. 2002. Champaign, IL, Engineer Research and Development Center [CERL].

Deal, Brian, D Fournier, D Timlin. (2002) *An Assessment of Encroachment Mitigation Techniques for Army Lands*. Engineering Research and Development Center [CERL]. TR-02-27.

Fang, Shoufan, James Westervelt, George Z. Gertner, and Alan B. Anderson (2006) *Procedure for Estimating Weights of LEAM: User's Guide,* ERDC CERL SR-05-59.

Fournier, Donald F., Brian M. Deal, Elisabeth M. Jenicek, and Adam J. Sagert. (2002) *Sustainable Installation Risk Assessment and Stationing Implications*. Engineer Research and Development Center [CERL], Champaign, IL, SR-02-12

Jenicek, Elisabeth M., Natalie Downs, Brad Boesdorfer, and Donald F. Fournier, (2006) *A Comparison of Regional Vulnerability Factors for Department of Defense (DOD) Installations*, Technical Report, 24 Aug 06, ERDC-CERL, Champaign, IL, Report Number ERDC/CERL TR-06-22.

Jenicek, E.J. et al. (2004) *The Sustainable Installation Regional Resource Assessment (SIRRA) Capability: Version 1*, Report Number ERDC/CERL TR-04-9

Jenicek, Elisabeth M., Brian M. Deal, and Adam J Sagert (2002) *Sustainable Indices and Metrics: An Annotated Bibliography*. TR-02-25. Champaign, IL, Engineering Research and Development Center

MacAllister, Bruce, Robert Lozar, James Westervelt, Michael White, and Joseph Rank (2006) *Fort Knox Trend Analysis, Encroachment Study, and Perimeter Expansion Opportunities in Support of Military Training,* Report Number ERDC/CERL TR-06-3.

Myers, Natalie R.D., James D. Westervelt, Jeff Terstriep, and William D. Goran , *Landuse Evolution and Impact Assessment Model* , Report Number ERDC/CERL TN-01-2, rev. Aug 2006 (2001)

Timlin, D., D. Jonhston, and Brian M. Deal. Guidelines for Developing Historic Urban Growth Series for Military Installation Risk Assessment. TR-02-06 (January). 2002. Champaign, IL, Engineer Research and Development Center [ERDC], Construction Engineering Research Laboratory [CERL].

Westervelt, James, and MacAllister, Bruce. (2006) *Quick Predictions of Future Training/Testing Opportunities Using mLEAM*. ERDC/CERL TR-06-27. Champaign, Illinois, US Army Corps of Engineers Engineer Research and Development Center.

Westervelt, James, and Joseph Rank. (2006) *LEAMram: Residential Attractiveness Model*. ERDC/CERL TR-06-28. Champaign, Illinois, US Army Corps of Engineers Engineer Research and Development Center.

Westervelt, J. (2004). *Approaches for Evaluating the Impact of Encroachment on Installation Training/Testing*. ERDC/CERL TR-04-04. Champaign, Illinois, US Army Corps of Engineers Engineer Research and Development Center.

Westervelt, James, Kyle Brock, Woonsup Choi, and Yong Wook Kim. (2004) *Development of Input Maps for the military Land use Evolution and Assessment Model (LEAM) Land Use Change (LUC) Simulation Model*. ERDC/CERL TR-04-24. 2004. Champaign, Illinois, US Army Corps of Engineers Engineer Research and Development Center.

7.1.3 Conference Presentations

Case, M., Brian M. Deal, William Goran, R. Lacey, and James Westervelt. 2002. *Fort Future: Installation Transformation Using A Virtual World*. Paper presented at The US Army Science and Technology Conference.

Choi, Woonsup. 2005. *Spatial Frequency Analysis (SFA) of Urban Land Cover in Dynamic Spatial Modeling of Urban Development*. Paper presented at University Consortium for Geographic Information Science (UCGIS) 2003 Summer Assembly, at Pacific Grove, California (June).

Choi, Woonsup and Bruce Hannon. 2005. *Modeling Hydrological Impacts of Anticipated Urban Growth in the Midwestern U.S.* Paper presented at Association of American Geographers 101st Annual Meeting (April), at Denver, Colorado.

Choi, Woonsup, Yun Wang, and Brian M. Deal. 2004. *Long-term Impacts of Land Use Change on Non-point Source Pollutant Loading for St. Louis Metropolitan Area*. Paper presented at Illinois Water 2004, at Urbana, Illinois (October).

Choi, Woonsup. 2004. *Future Impacts of Urbanization on Runoff and Water Quality*. Paper presented at 100th Annual Meeting of the Association of American Geographers, at Philadelphia, Pennsylvania (March).

Deal, Brian M. 2005. *Evolving Urban Dynamics: the Land use Evolution and Impact Assessment Model*. Paper presented at Planning Matters: a workshop of the Illinois Planning and Zoning Institute (March).

Deal, Brian M. 2004. *Land Use Change and Transportation Modeling: A Synergy of Models*. Paper presented at Featured speaker at The Transportation Engineering Association of Metro St Louis annual meeting, at St Louis, MO (February).

Deal, Brian M. 2003. *Sustainable Land-Use Planning: The Integration Of Process And Technology*. Paper presented at Invited speaker at The Illinois Facility Conference and Expo, at Illinois State University (August).

Deal, Brian M. 2003. *Land use Change and Transportation Modeling: Metro Transportation Models and LEAM*. Paper presented at Invited speaker at The Midwest Transportation Planning Conference, at St Louis, MO (June).

Deal, Brian M. 2003. *The Land use Evolution and impact Assessment Model (LEAM): applications to hydrologic processes*. Paper presented at Invited speaker at The Hydrologic Seminar Series at Purdue University, at West Lafayette, IN.

Deal, Brian M. 2003. *The Modeling Process and Stakeholder Interaction*. Paper presented at Livable Communities Conference., at University of Missouri, St Louis (April).

Deal, Brian M. 2003. *Planning for Smart Growth*. Paper presented at American Planning Association Conference, at Denver, CO (March).

Deal, Brian M. 2001. *An Operational Model for Sustainable Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities*. Paper presented at The Joint Services Pollution Prevention Conference, at San Antonio, TX (August).

Deal, Brian M. 2001. *The Land use Evolution and Impact Assessment Model: a distributed modeling environment*. Paper presented at Invited presentation at The USGS Urban Dynamics Workshop

Deal, Brian M. 2001. *Urban Dynamics and Sustainability: and Ecological Approach*. Paper presented at American Collegiate Schools of Panning Conference, at (November).

Deal, Brian M. and Varkki George Pallathucheril. 2001. *Ecological Sustainability and the Urban Dynamics: A Disaggregated Modeling Approach to Sustainable Design*. Paper presented at Computers in Urban Planning and Urban Management, at Honolulu, HA (July).

Deal, Brian M. and Varkki George Pallathucheril. 2001. *Ecological Sustainability and the Urban Environment*. Paper presented at The Environmental Design and Research Association Conference, at Glasgow, Scotland (July).

Goran, William, Brian M. Deal, T Aden, and D. Timlin. 2000. *Urban Growth: A Challenge to Sustaining U.S. Department of Defense Land Uses*. Paper presented at Bioregional Planning: Resources Management Beyond the New Millennium, at Australia.

Sun, Zhanli and Brian M. Deal. 2004. *A Spatially Explicit Urban Sprawl Simulation Model: Land-use Evolution and impact Assessment Model (LEAM)*. Paper presented at Urban and Regional Information Systems Association Annual Conference, at Reno, Nevada.

Westervelt, J.D. 2006, *Projecting Loss of Training Opportunities Due to Urban Development*, ITAM Conference, Fort Riely, Kansas, August, 2006

Westervelt, J. D., Michael White, and David Stigberg 2006, *Planning for Noisy Activities Within Urban Patterns*, FOSS4G Conference, Lausanne, Switzerland, September, 2006

Westervelt, J. D. 2006, *GIS-based Urban Growth Simulation Modeling*, FOSS4G Conference, Lausanne, Switzerland, September, 2006

Westervelt, J. D., B. Deal, M. Davis 2005, *Urban Encroachment Analysis of the Norfolk Area*, 2nd DOD Sustainable Ranges Initiative, August 22-25, San Antonio TX.

Westervelt, J. D., M. White, D. Morrison, M. Kemme, M. Ginsberg 2005, *Where Can I Train?,* 2nd DOD Sustainable Ranges Initiative, August 22-25, San Antonio TX.

Westervelt, J. D., Byrd, A., Russell, S. 2004, *Connecting proposed regional plans to future hydrologic implications*, presented at the Ecological Society of America Annual Conference, Portland, Oregon

Westervelt, J. D., W.D. Goran, and J.M. Davis 2004, *Future Land Dynamics: Linking Changes to Range Sustainability*, Sustainable Range Management, January 5-8, New Orleans, LA.

7.2 Complementarity with RSim

This section was jointly developed with Dr. Virginia Dale of the Oak Ridge National Lab and PI of parallel project SI-1259 in response to SERDP IPR requests to both projects.

Wording of action item:

> In your Final Report, due December 2006, discuss the complementarity between your RSim models and the mLEAM models developed under SERDP project SI-1257 and describe how the two research products can best fit together in a toolkit for DoD land managers. Prepare this portion of your report in coordination with project SI-1257. In this report also include a discussion on how receptive your models will be to different data formats, the degree to which model algorithms have been validated, and what future modeling components may be important to add (for example, the impact of prescribed burns and wildfires on regional air quality).

7.2.1 Introduction

This part of the final report discusses the complementarity between the RSim model and the mLEAM models developed under SERDP project SI-1257 and describes how the two research products can best fit together in a toolkit for Department of Defense land managers. The section on complementarity was developed by members of both teams of researchers from SI-1259 and SI-1257. The report also includes a discussion on how receptive RSim is to different data formats, the degree to which model algorithms have been validated, and what future modeling components may be important to add (for example, the impact of prescribed burns and wildfires on regional air quality).

This report begins with an overview of each of the models as well as a short description of Fort Future, for it may serve as a vehicle for integration. A comparison of end-user delivery approaches of the models is also included, for it points out some of the needs for integration. The report concludes with a section on RSim's data formats, validation and future needs.

7.2.2 Complementarity between the RSim model and the mLEAM models

Overview of RSim

The Regional Simulator (RSim) is a computer model designed to integrate land-cover changes with effects on noise, water and air quality, and species of special concern and their habitats. The RSim model was developed for the region around Fort Benning, but was designed so that its basic framework can be applied to other military installations and their regions, thus ensuring broad applicability to DoD environmental management concerns. RSim uses nationally available data sets and addresses concerns common to many installations.

Where possible, RSim was built from existing models. Urban growth is based upon the SLEUTH model (Clarke et al. 1998, Clarke and Gaydos 1998, Candos 2002), and transitions for the non-urban land cover are based on change detection of those observed for the five-country region (Baskaran et al. 2006A). The water quality module uses nutrient export coefficients combined with information on the area of different land uses and/or land covers to predict the annual flux

of N and P from terrestrial watersheds. The noise module uses GIS data layers of military noise exposure developed by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) as part of the Fort Benning Installation Environmental Noise Management Plan (IENMP). The Air Quality module estimates the impact of emissions changes on ozone air quality using sensitivity coefficients available the Fall Line Air Quality Study (http://cure.eas.gatech.edu/faqs/index.html). The module that predicts habitat for the gopher tortoise (*Gopherus polyphemus*) was based on analysis of locations of gopher tortoise burrows at Fort Benning and tested for the larger five-country region (Baskaran et al. 2006B). The module predicting habitat for red cockaded woodpecker was based on data from the region.

Numerous future scenarios can be modeled using RSim. These include both civilian and military land-cover changes. RSim includes four specific types of scenarios, along with their impacts on environmental conditions over the next 10 to 40 years: (1) modeled urbanization (conversion of non-urban land cover to low-intensity urban and conversion of low-intensity to high-intensity urban), (2) planned road expansion plus modeled urbanization, (3) a new training area at Fort Benning, and (4) hurricanes of various intensities.

RSim includes a user-friendly interface that also documents the particular components of the model. For example, potential ranges on parameter values are listed and the user is not allowed to enter values that exceed these ranges. Furthermore, the equations and reasoning behind the model are explained. The glossary defines key terms. The use of RSim software involves the following steps:

1. RSim introduction
2. Select scenarios
3. Urban growth model options
4. Land cover transition options
5. Water quality module
6. Air quality module
7. Noise module
8. Species and habitat module
9. Review simulation selections
10. Simulation status
11. Simulation results

As the user moves through the RSim interface, the right part of the screen tracks the current status of the user according to the eleven steps.

Each real-time run of RSim is designed by the users to address their particular needs. The user can choose to include any combination of the modules and change parameter values as well. The code is written in Java with an object-oriented design, and this is not dependent on any particular software and can run on any computer. The spatial resolution is a 30-m pixel and the common temporal resolution across the modules is one year. The interface also provides text, tabular and mapped outputs that the user can save for report development or subsequent analysis.

RSim is intended to be run in learning mode so that users can gain knowledge about potential outcomes of particular decisions and therefore modify decisions and then explore those outcomes. Thus the use and application of RSim are highly related to the users' needs and perspectives.

Overview of LEAM

LEAM is short for "Land use Evolution and Impact Assessment Modeling". It is a synthesis of approach and software that allows a regional planning stakeholder community to explore the long-term (20-40) year consequences of proposed regional plans. The LEAM approach has been successfully applied to regions containing Peoria, Illinois; East St. Louis and St. Louis, Missouri; Traverse City, Michigan; and now the Chicago Metropolitan Area extending across Wisconsin, Illinois, and Indiana. It has also been tested with the Fort Benning and Scott Air Force Base communities. Generally speaking, the LEAM approach proceeds as follows:

10. A quick generation of urban growth is completed using nationally available data.
11. Results are presented at a regional planning charrette which then poses the following questions to participants:
    - What is right and what is wrong with the projections?
    - What local data and information is available to replace the national data?
    - What are the perceived encroachment problems/challenges?
    - What are the local drivers to growth?
    - What regional planning ideas should be tested?
12. The LEAM urban growth model is modified, including changes to the source code, to capture the needs identified in the charrette. A 9 or 20 sector economic model is used to project future economic and population growth based on proposed major changes in employment (e.g. installation mission changes).
13. The model is calibrated – often with historic census data
14. Revised model outputs are reviewed by the stakeholder community until they are satisfied with the base model projections.
15. Regional planning proposals are tested with the model
16. As needed/requested, future urban patterns are input into various models such as:
    - Transportation models
    - Habitat fragmentation models
    - Economic impact models
    - Utility (e.g. water, electric grid, and sewer) models
17. Results are captured in a report for general public consumption and presented at regional stakeholder meetings
18. The new localized LEAM model often becomes part of the regular tools of the community to test further regional planning suggestions.

Each full application of LEAM results in an urban growth model specially created to address the specific needs of the target communities. Step 1, above, is accomplished with a generic version of LEAM's land use change model. This software is written in the "C" language and, like RSim, owes its beginnings to the SLEUTH model. It is 30-meter grid-cell based, uses a 1-year time step, and generates future urban patterns across a region based on calculated dynamic attractiveness of undeveloped areas to new urban residential, commercial, and open-space. Raw GIS maps are processed with in-house ESRI GIS scripts to create the needed input files for the LEAM land use change model. Results of the model are further processed with ESRI-GIS for reporting and image production purposes.

LEAM applications are tailored to meet the specific needs of target communities and rely heavily on intensive interactions with multiple stakeholders across a region.

Overview of mLEAM

While LEAM provides a powerful approach designed to specifically address the regional planning challenges facing a community composed of many stakeholders, mLEAM provides a very inexpensive and quick, though generic, approach to project residential growth around military installations and forecast the implication of that growth on future military training and testing opportunities. mLEAM analyses begin with a GIS technician downloading free and nationally available data such as land cover (NLCD), elevation (DEM), roads/highways, and state/federal lands. These are processed to generate raster and vector maps in a common UTM projection and common area extending through a defined set of counties. These maps are then loaded with scripts into the Linux/Unix based GRASS GIS and automatically processed. There are three primary steps.

4. LEAMram is the residential attractiveness model that generates a residential attractiveness map based on the combined attractiveness of each 30-meter square area with respect to distances to roads, highways, interstates, intersections, employment, other residential, trees, and water. The attractiveness is measured through an analysis of the current pattern of residential areas across the study area.
5. LEAMluc is a version of the LEAM land use change model. Only residential development is generated however because the primary incompatible land use challenge involves military activities and residential.
6. LEAMtom is the training opportunities module, which runs a number of new GIS analyses that predicts the probability of complaints from residential neighbors in response to military generated noise, dust, and smoke. Night sky illumination due to city lights is also synthesized.

Each of these steps generates results not only within the GRASS GIS, but automatically to a web site for immediate end-user viewing. Posted results include text, map images, urban growth movies, and GIS maps for downloading into a user's local GIS software.

Overview of Fort Future - LEAM

Fort Future is a Corps of Engineer's funded R&D program that provides a framework for providing Web-browser based simulation modeling tools that allow installation planners to simulate the consequences of on-installation construction on utility systems, to test the impact of utility failures (e.g. from terrorist attacks), to design new buildings and new sites for buildings, and to run LEAM models. The Fort Future LEAM (FF-LEAM) prototype is expected to be running for demonstration purposes in the Fall of 2006. The interface is expected to allow a user to open a standard browser to access the Fort Future web toolbox site. For FF-LEAM, the user will be provided with a map of the United States showing counties. After zooming to an area of interest, the user will select a coterminous set of counties and request automated mLEAM runs. After validating the request as reasonable (e.g. not too big), the system will schedule simulation runs, run the request, and email the user when the results are completed and posted for viewing. The Fort Future web-based software environment has been designed to accommodate the generation and operation of Web-based GUIs through the construction of XML text files.

Comparison of End-User Delivery Approaches

RSim, mLEAM, LEAM, and Fort Future have distinctly different approaches and philosophies for delivering capabilities to end users. RSim and LEAM are designed to deliver final capabilities to a local geographic community by tailoring the software, data, and analyses in direct response to locally unique needs. Therefore, application of RSim or LEAM requires that the development group create a new instance of the capabilities. The RSim interface can be provided to the user via CD or the web, which allows users some latitude in posing scenarios without involving the development group. The user can readily develop reports with text, tables, and maps derived from their particular combination of conditions and scenarios. The interface documents the conditions under which the model can be run and provides suggestions for adaptation of RSim to special applications. LEAM developers deliver results to the user community, but not the models. Results are primarily in the form of color reports filled with images and interpretations, but can include GIS map files. mLEAM, like RSim can be delivered to end users, but is in a form useful only to computer technicians familiar with Unix/Linux and GRASS. A set of technical reports have been published that will help the technicians apply mLEAM to other locations. Fort Future LEAM is designed to allow virtually anyone with a Web browser to run mLEAM (or LEAM) simulations. The development/delivery philosophies for applying the models to a new area can be summarized as follows:

- The RSim philosophy is to provide an end user with the ability to run scenarios on any computer or computer operating system using models specifically tailored for the target area and using nationally available data sets. Adapting the model to a new area can most easily be done by the developers of RSim but could be attempted by others.

- The mLEAM philosophy is to provide an end user with a quick way to generate generic urban growth and military impact analyses using nationally available data sets. Users can contract with developers or work with local GIS techs.

- The LEAM philosophy is to deliver analysis and results of urban growth simulation using models tailored to the needs of local planners, calibrated to local trends, using local data, and through the integration of urban growth impact analyses as needed.

The Fort Future LEAM philosophy is to allow anyone to run mLEAM-type analyses for anywhere in the country – through their Web browser.Development of an integrated capability will begin by carefully stating the questions that end users will be able to ask, the expense in time and money the user will accept, the accuracy and detail needed by the user, and the skills of the user. Based on this a product development and delivery approach will be defined – followed by design and development.

7.2.3 References

Baskaran, L., V. Dale, C. Garten, D. Vogt, C. Rizy, R. Efroymson, M. Aldridge, M. Berry, M. Browne, E. Lingerfelt, F. Akhtar, M. Chang and C. Stewart. 2006A. Estimating land-cover

change in RSim: Problems and constraints. *Proceedings for the American Society for Photogrammetry and Remote Sensing 2006 Conference*, Reno, NV, May 1-5 2006.

Baskaran, L.M., V.H. Dale, R. A. Efroymson, and W. Birkhead. 2006B. Habitat modeling within a regional context: An example using Gopher Tortoise. American Midland Naturalist 155: 335-351.

Beaulac, M.N., and K.H. Reckhow. 1982. An examination of land use – nutrient export relationships. *Water Resources Bulletin* 18: 1013-1024.

Clarke, K.C., L. Gaydos, S. Hoppen S. 1996. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, *Environment and Planning* 24:247-261.

Clarke, K.C., L.J. Gaydos. 1998. Loose-coupling a cellular automation model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore, *Geographical Information Science* 12(7):699-714.

Candau, J. C. 2002. Temporal calibration sensitivity of the SLEUTH urban growth model. M.A. Thesis. University of California, Santa Barbara.

Frink, C.R. 1991. Estimating nutrient exports to estuaries. Journal of Environmental Quality 20: 717-724.

Garten, C. In press. Predicted effects of prescribed burning and harvesting on forest recovery and sustainability in southwest Georgia, USA. *Journal of Environmental Management.*

Johnes, P., B. Moss, and G. Phillips. 1996. The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management. *Freshwater Biology* 36: 451-473.

Johnes, P.J. 1996. Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient approach. *Journal of Hydrology* 183: 323-349.

Mattikalli, N.M., and K.S. Richards. 1996. Estimation of surface water quality changes in response to land use change: application of the export coefficient model using remote sensing and geographical information system. *Journal of Environmental Management* 48: 263-282.

U.S. Army. Army Regulation 200-1. 1997. Environmental Protection and Enhancement. Washington, DC: U.S. Department of the Army, Washington, DC.

7.3 Feasibility and Utility of Combining RSim and LEAM

7.3.1 Background:

Research projects SI-1257 and SI-1259 were funded by the Strategic Environmental Research and Development Program (SERDP) to build simulation models that address issues of encroaching development around military installations and their implications on both the installation's mission and the condition of the region. The resulting products, RSim, LEAM, and mLEAM, represent a suite of analysis approaches, software tools, and techniques for helping installations identify, predict, and address encroachment challenges.

To evaluate the feasibility and utility of synthesizing the modeling tools being provided by SERDP SI 1259 and SI 1257, the RSim team held a workshop to identify the strength of the RSim approach and had productive conversations with mLEAM researchers to discuss integration approaches. Because the similar process in the two modeling approaches is urban land cover, the way that urban land cover is modeled by the two approaches needs to be described before the concept of synthesizing the tools can be discussed. The next sections first discuss the utility of a combined approach and then compare the way urban land-cover changes occur in the different models. The last section discusses the technical feasibility of synthesizing the modeling tools.

7.3.2 The Utility of Combing the RSim Approach with the mLEAM Approach:

The value of combining the RSim and the mLEAM approaches is the breadth and diversity of questions that can be addressed, processes evaluated, and decisions considered. RSim focuses on a diversity of outcomes: how land-use decision affects the quality of the air, water, noise and species and their habitat. It can be run under explicit scenarios of urban growth, military use, road development and hurricanes. These changes are underlain by changes in 18 land cover categories (including developed, barren, forested upland, shrubland, non-natural woody land, herbaceous and wetland classes). LEAM connects proposed regional plans with long-term consequences to transportation networks, utilities, habitat fragmentation, and services such as schools. The mLEAM models focus on providing projections of urban residential patterns and their direct impact on suitable military training/testing areas. Together these models cover a great diversity of cause and effects. Because each model allows some feedbacks, the combined model could be used to explore interactions that might display nonlinear dynamics. Combining the capabilities of the model suites could provide installation and regional planners with the following set of capabilities:

- Explore potential outcomes of a variety of decisions under different scenarios of future change.
- Project economic and population changes in regions based on proposed installation mission changes.<Does LEAM really have population changes in it – or is it just change in urban land cover?>
- Forecast future land-cover changes and patterns across regions
- Forecast effects of changes in the region due to
    - Urban growth (under typical conditions for the region or other scenarios)
    - Natural disturbances such as hurricanes
    - Changes in the road system
    - New military training areas
- Evaluate the impact of future land-cover changes and their patterns on
    - Habitat suitability
    - Military training/testing suitability
    - Water quality
    - Hydrology
    - Air quality
    - Transportation system loads
    - Economic and social impacts
    - Noise conditions

7.3.3 A Focus on Urban Land-Use Change as a Way to Integrate RSim and mLEAM:

The key process that is common to the RSim and LEAM/mLEAM land-use change models is urban land-cover change. Both approaches start with initial conditions of a particular spatial configuration of urban lands and project changes over time in urban land use. However the forces that affect urban land cover are quite different in the two approaches.

The mLEAM models simulate changes in urban patterns in response to local, county and state planning. Planning decisions that can be made by users relate to such features as locations of new highways, construction of highway ramps, major land purchases, purchases of development rights construction of news roads, zoning plans, or installation buffers. Hence the LEAM/mLEAM approach focuses on forecasting results of planning decisions. These planning proposals essentially establish the "playing field" upon which residential developers build new homes and neighborhoods and homebuyers purchase their residences, industrial developers create new industrial/commercial areas, and city planners establish new parks and open spaces. The LEAM land-use change model then forecasts these decisions and resulting regional land-use patterns. (mLEAM uses only the residential projection component.) Based on population projections using a multi-sector economic input-output model, target growth in commercial, residential, and open space is pre-calculated. The LEAM land-use change model then converts developable, but undeveloped land within the region based on the pre-calculated needs and the relative attractiveness of land to each use. The new development then affects the attractiveness of each cell to development, which is recalculated. This process occurs in one-year time steps. The result is captured in two maps. The first is the final land-use map using the National Land Cover Data (NLCD) categories as the starting land-use map. The second captures the time step at which each cell changed. Using these two maps and the starting map, it is simple with a GIS to generate the land use at any time step or to create a movie showing the land-use change over simulation time.

RSim simulates changes in urban land by a rule-based model (Clarke et al. 1998, Clarke and Gaydos 1998, Candos 2002). RSim includes both spontaneous growth or new urban areas and patch growth (growth of preexisting urban patches). Growth occurs in either low-intensity[1] or high intensity[2] urban areas. Any non-urban cells can become low-intensity urban cells according to three rules: spontaneous growth occurs in a set number of random cells; new spreading growth occurs in random cells and two neighboring cells, or edge growth arises from a random number of non-urban pixels with at least three urbanized neighboring cells. This approach to modeling urban growth was derived from the SLEUTH model (http://www.whrc.org/midatlantic/modeling_change/SLEUTH/sltuh_overview.htm).

Low-intensity urban pixels become high-intensity urban cells according to different rules for two types of desired high-intensity urban cells:

- central business districts, commercial facilities, high impervious surface areas (e.g., parking lots) of institutional facilities that are created within existing areas with a concentration of low-intensity urban cells; and
- industrial facilities and commercial facilities (malls) that are created at the edge of the

1 Low-intensity urban land includes single family residential areas, urban recreational areas, cemeteries, playing fields, campus-like institutions, parks, and schools.
2 High-intensity urban land includes central business districts, multi-family dwellings, commercial facilities, industrial facilities, and high impervious surface areas of institutional facilities.

existing clumped areas of mostly low-intensity urban cells or along four-lane roads.

For the first high-intensity category, land-cover changes occur in a manner similar to changes in low-intensity growth, as described above: a spontaneous growth algorithm converts random low-intensity pixels to high-intensity pixels, and an edge growth algorithm converts random low-intensity urban pixels with high-intensity urban neighbors to high-intensity pixels. The second type of conversion from low-intensity to high-intensity urban land use is road-influenced growth.

RSim is initiated with the 1998 land-cover data for the west central Georgia study region that was obtained from the Natural Resource Spatial Analysis Laboratory, University of Georgia and classified into 18 NLCD categories. In addition to considering urban growth, RSim simulates changes in non-urban land cover (i.e., change in forests, cropland, barren area, and so on). In order to incorporate the growth and changes that may happen in non-urban land-cover types, an analysis of past growth trends helped to set specific growth patterns and trends for the future. This approach is based on the assumption that growth trends remain constant over the years of analysis and over the spatial area being considered. Since forest management activities are different within Fort Benning and the surrounding private lands, the transition rules were calculated only for regions outside Fort Benning. The land inside the Fort Benning military reservation is maintained for training exercises.

7.3.4 The Technical Feasibility of Synthesizing the Modeling Tools Provided by SERDP SI 1259 and SI 1257:

Using urban land use as a common process, it seems entirely possible to combine the tools provided by RSim and mLEAM. The models have the same spatial resolution (30 m pixels) and temporal resolution (1 year).

One challenge that must be met is using a common computer language and developing a common code. RSim is written in Java with an object-oriented design and thus does not rely on any particular software (although it produces maps compatible with ARC-INFO or with any text editor or spread sheet software). It also was designed to use data sets that are available across the United States. The LEAM/mLEAM land-use change model is written in the C programming language. LEAM relies heavily on Windows-based ESRI-based processing and analysis scripts, while mLEAM relies on Linux/Unix scripts and the GRASS GIS for map analyses and spatial output. Combining the software products would require the expertise of a computer scientist.

Because urban land cover is the common process, the values for urban land cover would serve as the interface between the two modeling approaches. The mLEAM models project changes in three categories of urban cover (residential, commercial, and open space). RSim projects changes in two categories of urban cover (low intensity urban and high intensity urban). In order to relate changes in urban land cover of the RSim and mLEAM models, we will need to carefully define the relationship between the two ways of categorizing urban land. However, once this definition is done, then the computer codes should be able to be modified so that the user would have access to the full abilities of both RSim and mLEAM.

Combining and adopting the full system for the Fort Benning region is the obvious first step. Before the combined model can be deployed to a new location, RSim must be adopted to a new region. Proposals have been developed to do this for Fort Bragg and for Camp Lejeune. mLEAM, on the other hand has already been designed to run in its “quick and dirty’ mode for

installations across the United States. Full application of LEAM in a particular region would require detailed work however.

One possibility for a framework in which to house the combined models is Fort Future™. The data and tools within Fort Future™ are designed to readily interface to help the Department of Defense address its planning requirements.

The development of such a combined approach would likely involve the following steps:

1. Identify an existing or new user panel that represents the target user community and is forward thinking and adapts/adopts new technology.
2. Demonstrate all capabilities to user panel
3. Obtain feedback on what they like, don't like, want, and need
4. Develop an end-user interface design
5. Present to user panel for acceptance
6. Design the computer architecture that will support the user interface
7. Develop the software
8. Conduct Alpha test
9. Develop the software to address needs identified in the Alpha test
10. Conduct Beta test
11. Refine the software to address needs identified in the Beta test
12. Release the combined product

References

Clarke K C, Gaydos L, Hoppen S. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, *Environment and Planning* 1996; 24:247-261.

Clarke K C, Gaydos L J. Loose-coupling a cellular automation model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore, *Geographical Information Science* 1998; 12(7):699-714.

Candau J C. Temporal calibration sensitivity of the SLEUTH urban growth model. M.A. Thesis. University of California, Santa Barbara. 2002.

7.4 Final Application Reports Prepared for Scott Air Force Base and Fort Benning

Fort Benning

Results of LEAM Simulations

US Army Corps of Engineers®
Engineer Research and Development Center

March 2006

Fort Benning
Results of LEAM Simulations

March 2006

Project is cooperatively executed by

University of Illinois
LEAM Laboratory

US Army Engineer Research and Development Center
Construction Engineering Research Laboratory

Support is provided by the Strategic Environmental Research and Development Program, the Department of Defense's corporate environmental research and development program, in partnership with the Department of Energy and the Environmental Protection Agency. In keeping with the Department of Defense's interests in maintaining military readiness for national defense, SERDP is committed to creating sustainable military communities.

LEAM development and applications are conducted and managed by a team of faculty, staff, and students from the University of Illinois at Urbana-Champaign.

US Army Corps of Engineers®
Engineer Research and Development Center

LEAM brings together expertise in substantive issues, modeling, high-performance computing, and visualization from the departments of Urban Planning, Geography, Economics, Natural Resources and Environmental Sciences, Landscape Architecture, Civil Engineering, the National Center for Supercomputing Applications (NCSA), ERDC Construction Engineering Research Laboatory, and private industry.

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The first regional planning workshop for the Fort Benning region took place in November 2005. This workshop gave fifteen key stakeholders at the installation and economic development and conservation organizations an opportunity to consider the future consequences of different public investments and land use policies on development patterns in the region. The discussion focused on key drivers of growth in the region, potential encroachment issues, potential implications of this growth on Fort Benning, and different future scenarios of relevance to the region.

The main analysis tool utilized is the Landuse Evolution and impact Assessment Model (LEAM). It has been developed to help coordinate complex regional planning activities by providing local stakeholders the ability to examine the future implications of current local policies and investments. The LEAM Training Opportunities Model is used extensively in this work to assess how future land use change may restrict military training and other mission related activities on an installation.

A "base" scenario and eight alternative scenarios (listed below) were modeled and analyzed for this work. The alternative scenarios are potential future transportation projects, economic development projects, urban infrastructure improvements, resource protection policies and development policies. These scenarios were selected based on the preferences expressed by workshop participants and the availability of data needed to run the scenarios.

This report outlines the resulting scenario modeling and analysis as suggested by the stakeholder group. It follows two previous documents: an initial Charrette Report (November 2005) and a Charrette Results Report (December 2005).

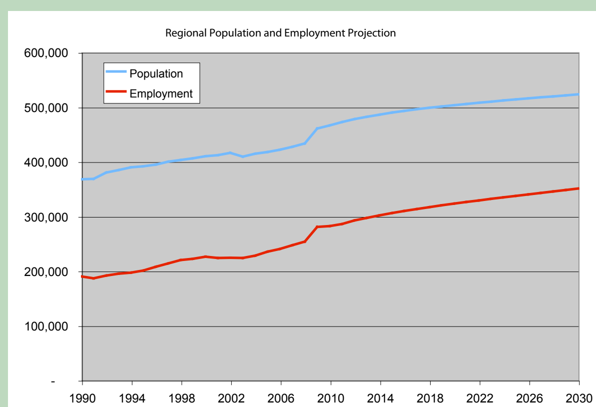
The following describes the results of the scenarios using LEAM and LEAMtom to illustrate how the proposed investments and policies may affect land use change and subsequent training opportunities at the installation over the next thirty years. In terms of the LEAM results, the description of the base scenario results includes maps of new development by square mile section in the region, and landuse change maps showing change for the immediate base region and a graph of growth over time by county. For each of the alternative scenarios, there is a map comparing the amount of new development by section of each alterative scenario with the base scenario, a map showing land use change compared to the base for key parts of the region projected to have the greatest difference, and a table showing each county share of new development. The LEAMtom results include maps showing how future urban development patterns can erode the installation's ability to conduct military missions.

Scenarios

1. Baseline
2. New Interstate 14
3. Expand Route 280 Through Base
4. New Sewer/Water Facilities South & East of Base
5. 431 Expansion & 431/165 Connection
6. New Industrials Parks & Marina/Museum Complex
7. Stream Buffer Protection
8. ACUB Protection
9. Higher Density Development

Economic Forecasts for the Region

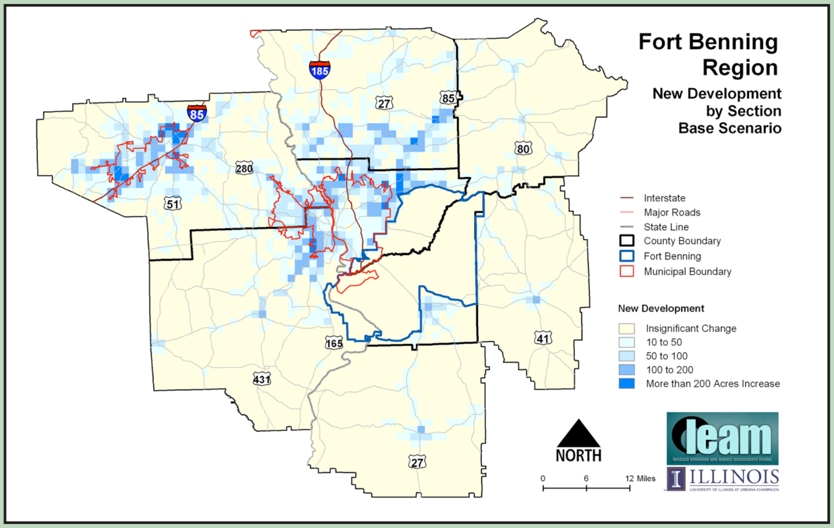
All of the scenarios are based on population and employment projections from the region-specific economic model developed at LEAM. The projections are based on how the national and regional economy is expected to grow over the next thirty years, and it includes the expected increase in troops and civilian workers at Fort Benning as a result of the recent BRAC. Employment is expected to increase by 125,000 and population is projected to increase by 113,000, for a total regional population of 522,000 by 2030. Based on these population projections, and our projections of average household size, housing vacancy and abandonment, and change in average housing lot size, over 43,000 acres of residential development is expected by 2030. Approximately 10,000 acres of commercial development is expected.

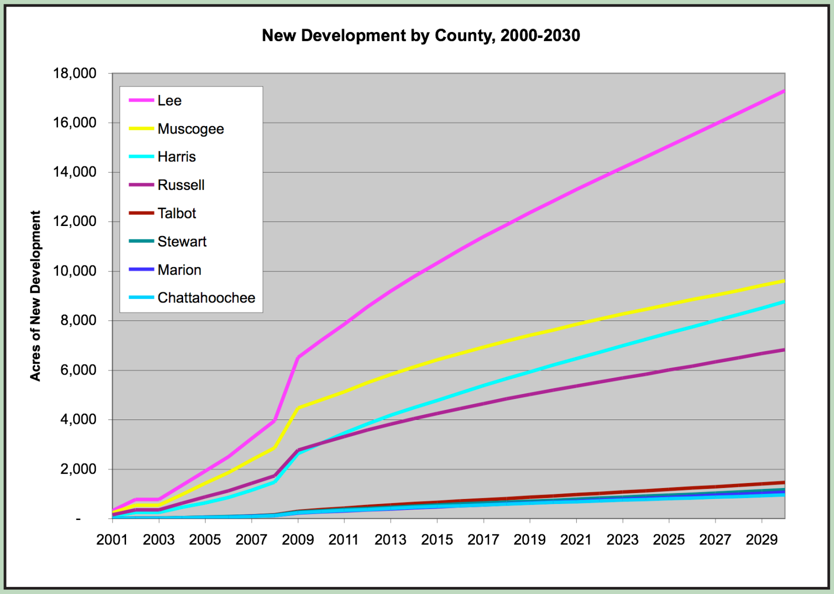


Base Scenario

To the right are figures illustrating the LEAM simulated future urban growth for the base scenario. This simulation assumes that economic and demographic trends continue as they have and recent past, as well as the increased level of troops and civilian workers expected as a result of the recent BRAC.

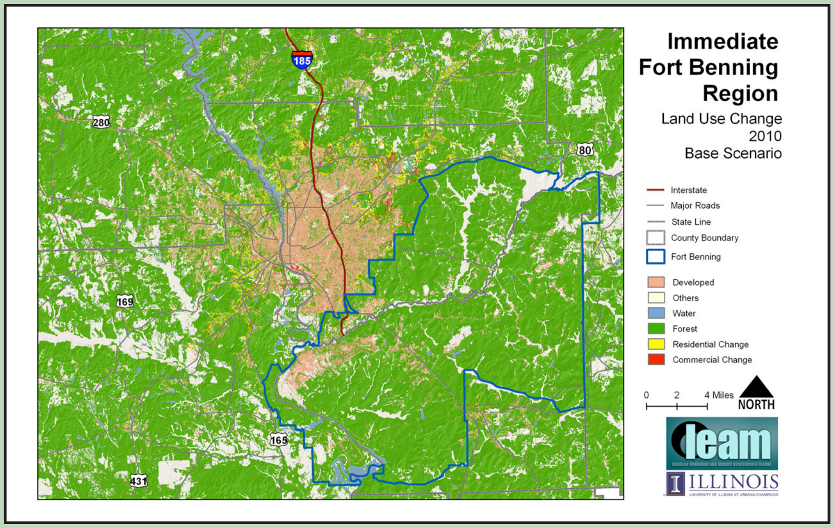
The first figure is a map that shows new development projected to occur (by square mile section) in the Fort Benning Region over the next thirty years (the darker blue indicates where more growth is expected). The map indicates that there are several significant growth areas in the region, including north of the installation (along US Route 80), north of Columbus (along US Route 27/State Route 85 and State Route 315), southwest of Columbus (along US Route 431 and State Route 165), and the Auburn/Opelika area.

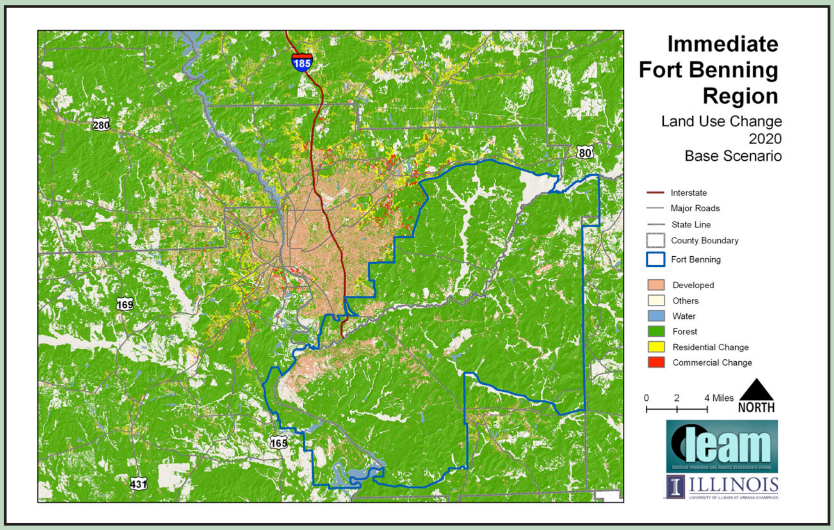


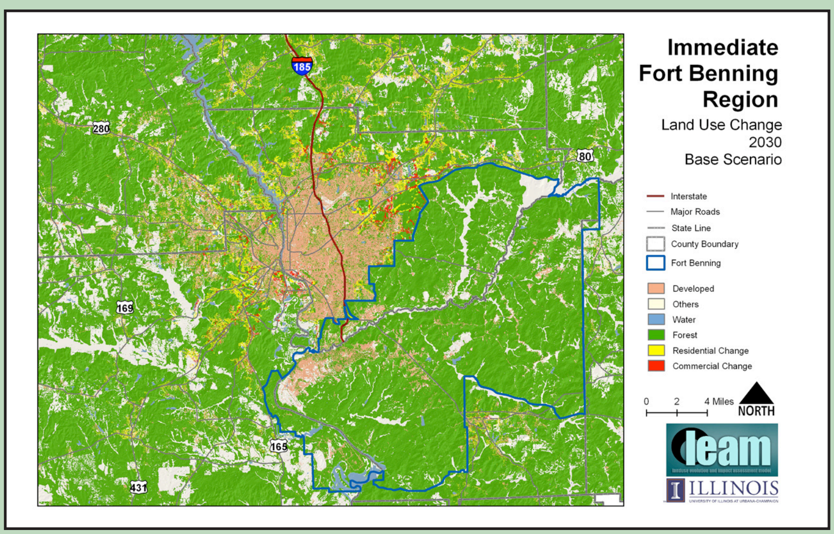


The second figure is a graph showing how much each county is projected to grow over the next thirty years. This figure shows a significant jump in urban growth in the region in 2008-2009 as more troops and civilian workers relocate to Fort Benning as a result of the BRAC. Following this jump, Lee County continues to have tremendous growth.

Over one-third (38%, over 17,000 acres) of the new development in the region from 2000-2030 is projected to occur in Lee County, and another 20% in Muscogee County. Harris and Russell County are also expected to have a significant share of regional growth (19% and 15%, respectively).







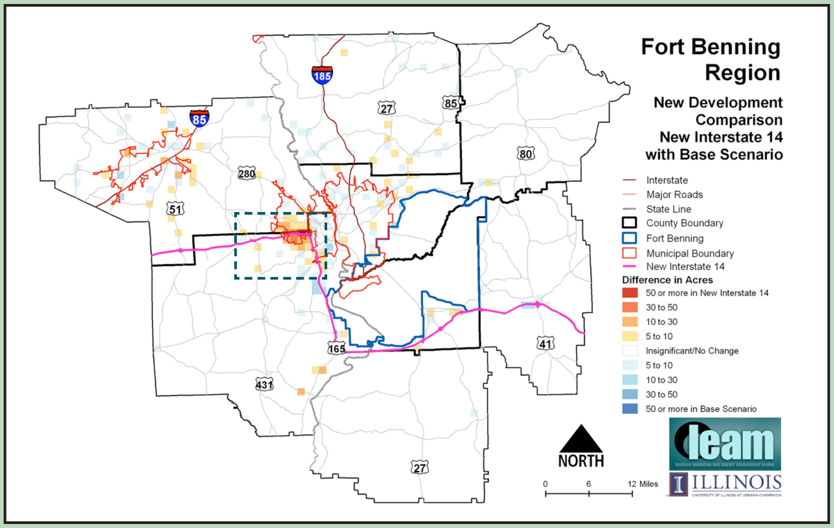
Each of the three maps show projected growth in the immediate Fort Benning region for 2010, 2020, and 2030. The yellow areas represent where future residential development is projected to take place, and the red areas where new commercial development will be seen.

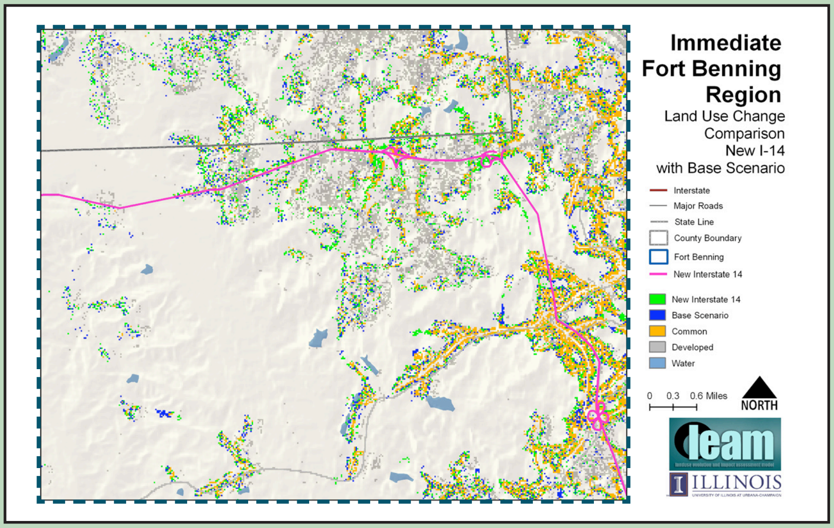
These maps indicate that there is a large amount of residential growth projected throughout the Columbus metropolitan area. Most of the commercial growth is expected to occur in the northeast and southwest portions of Columbus. In terms of how this may affect the installation, there is significant growth along the northern and northwestern boundaries of the base that could alter the installation’s mission capabilities in the northern part of Fort Benning. However, there is little growth near the southern portion of the installation.

New Interstate 14

To the right are images of LEAM simulated future urban growth for a scenario where a new interstate going across the region and south of the installation (see road location in top figure) Is completed.. This new interstate is expected to lead to more growth near the interstate, especially where there are interchanges near large urban areas, since it will make for a shorter commute from these areas to employment centers and city attractions.

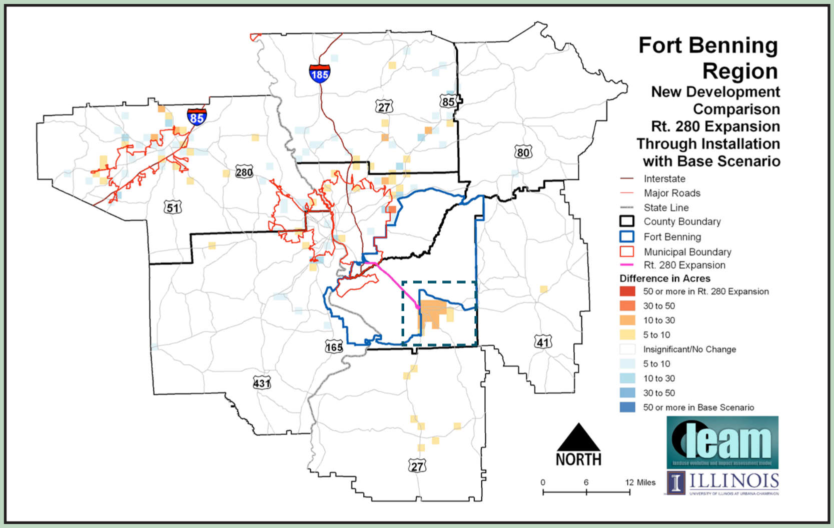
The LEAM results for this scenario show that, as expected, there will be significantly more development along the new interstate near the western edge of Columbus than there is in the base scenario. This increase west of Columbus is offset by less growth in scattered areas around Columbus, and one area of significantly less growth along the new interstate south of Columbus. The results do not show any significant movement of development closer to the base, except for a small increase in development directly south of the base in Cussetta. There is no major shift in growth among counties in the region.

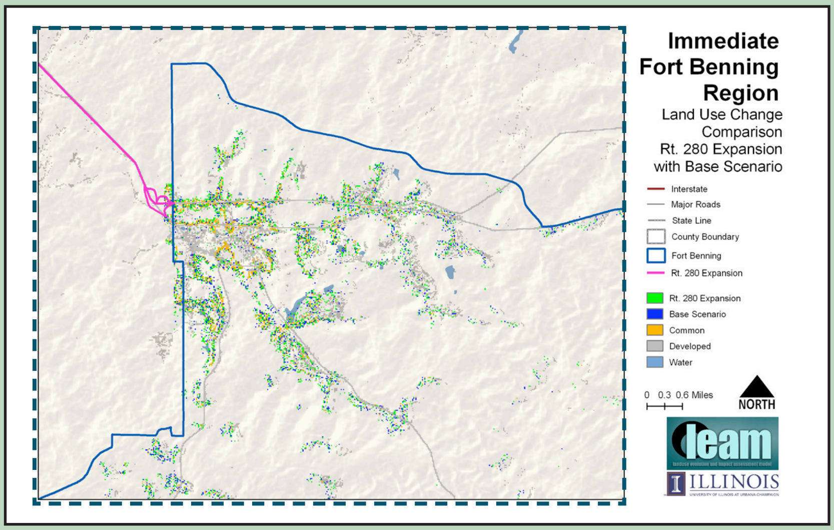




Share of 2000-2030 Urban Growth in Region

	Base	New I-14
Lee	36.7%	36.9%
Muscogee	20.4%	20.4%
Harris	18.6%	18.3%
Russell	14.5%	14.8%
Talbot	3.1%	3.0%
Stewart	2.5%	2.4%
Marion	2.3%	2.1%
Chattahoochee	2.0%	2.1%





Share of 2000-2030 Urban Growth in Region

	Base	Rt. 280
Lee	36.7%	36.4%
Muscogee	20.4%	20.5%
Harris	18.6%	18.3%
Russell	14.5%	14.4%
Talbot	3.1%	3.1%
Stewart	2.5%	2.7%
Marion	2.3%	2.2%
Chattahoochee	2.0%	2.5%

Expand Route 280 from Columbus to Cusseta

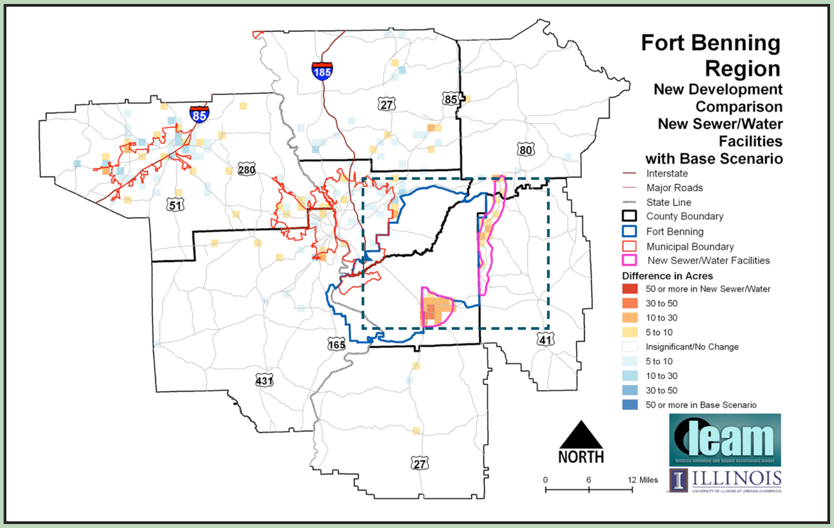
To the left are images of LEAM simulated future urban growth for a scenario where a limited access 4-lane widening of Route 280 from Columbus to Cusseta is completed. The expansion of Rt. 280 is expected to lead to more growth south of the installation, since it makes it easier to travel from Columbus to Cussetta.

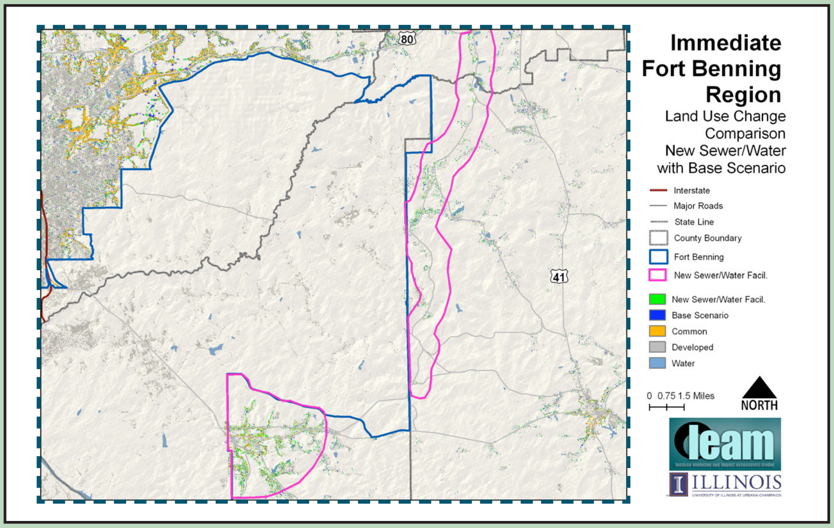
As expected, the results show there is significantly more growth in the Cussetta area in this scenario than there is in the base scenario. Areas with less growth are scattered around Columbus. Consequently, the road expansion leads to more development near the base at its southern boundary. There are no large shifts in growth expected among counties, with Lee and Chattahoochee Counties having some increase in growth and less growth in Harris County.

New Sewer/Water Facilities East & South of Base

To the right are images of LEAM simulated future urban growth for a scenario where additional sewer and water lines and facilities are completed in the Cusseta area and to the east of the base. The new infrastructure is expected to attract more development to these regions.

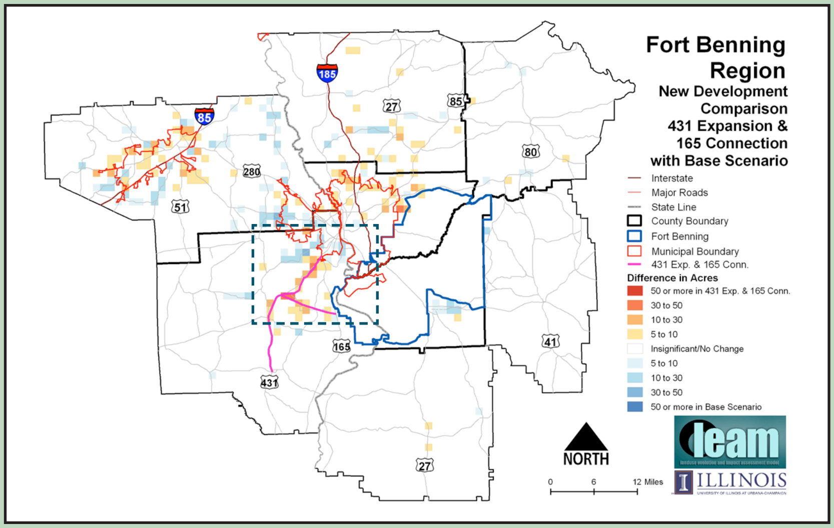
As expected, the results show there is a great deal more growth in the Cussetta area (one of the areas with improved infrastructure) in this scenario, and some additional growth in the area east of the installation expected to have new sewer and water infrastructure. Consequently, there is significantly more growth near the installation. The growth appears to come from the Columbus and the Auburn/Opelika area, where growth is lower in the base scenario. In terms of growth by county, Chattahoochee has significantly more growth in this scenario than in the base scenario, and Lee and Harris Counties have less growth than in the base scenario.

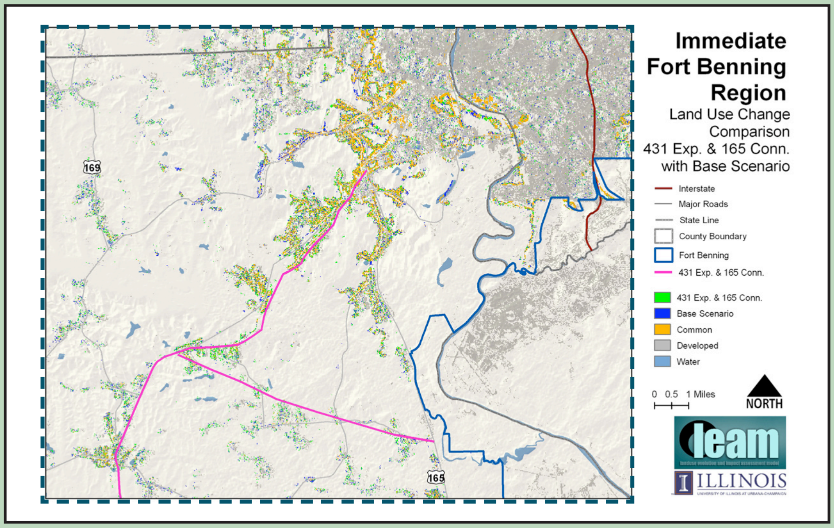




Share of 2000-2030 Urban Growth in Region

	Base	Sewer/Water Facilities
Lee	36.7%	36.3%
Muscogee	20.4%	20.2%
Harris	18.6%	18.2%
Russell	14.5%	14.5%
Talbot	3.1%	3.1%
Stewart	2.5%	2.4%
Marion	2.3%	2.4%
Chattahoochee	2.0%	2.8%





Share of 2000-2030 Urban Growth in Region

	Base	Expand 431 & 431/I65
Lee	36.7%	36.0%
Muscogee	20.4%	21.0%
Harris	18.6%	18.7%
Russell	14.5%	14.7%
Talbot	3.1%	3.1%
Stewart	2.5%	2.5%
Marion	2.3%	2.2%
Chattahoochee	2.0%	1.9%

431 Expansion & 431/165 Connection

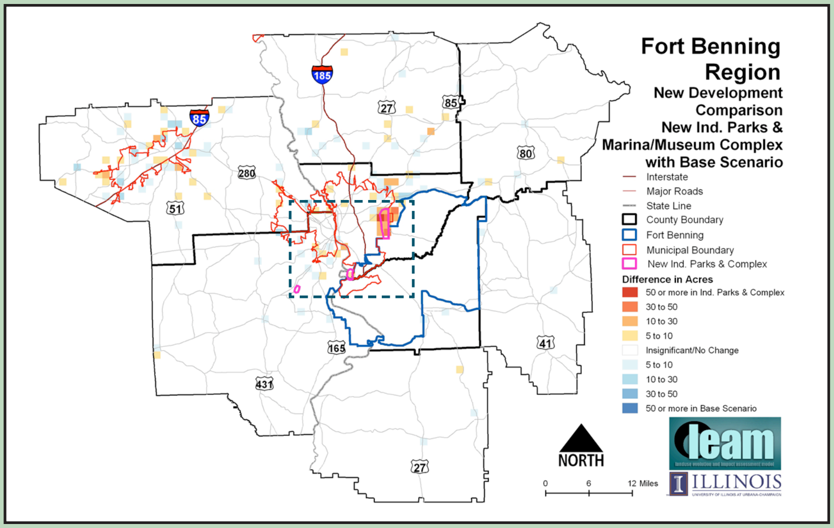
To the left are images of LEAM simulated future urban growth for a scenario where a stretch of 431 is expanded to four lanes and a new corridor connecting 431 and 165 is completed. These road improvements should lead to more growth near the road expansion areas, since the new roads will decrease driving time from these areas to Fort Benning and major employment centers in Columbus.

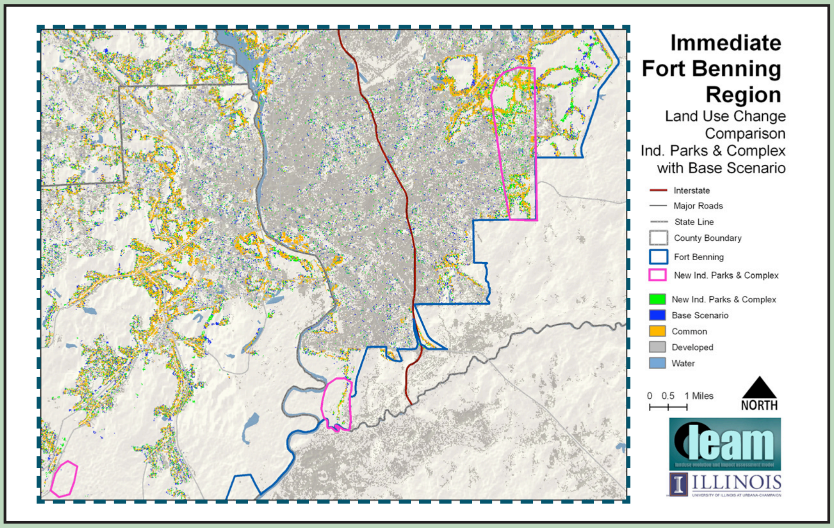
As expected, the results show there is significantly more growth in this scenario along Rt. 431 where it is expanded and along the new connector from Rt. 431 to 165. However, there also appears to be more growth in northern Columbus, which was not an expected outcome of this scenario. There is less growth in areas just north of where road upgrades will occur. This shift in growth moves development closer to Fort Benning at both the southwestern and northwestern boundaries, with a small decline in growth near the installation at Cusseta. In terms of growth by county in this scenario, there is more growth in Muscogee and Russell Counties and less in Lee County, relative to the base scenario.

New Industrial Parks & Marina/Museum Complex

To the right are images of LEAM simulated future urban growth for a scenario where two industrial parks and a Marina/Museum complex south of Columbus are established and there is a policy to provide incentives to develop in these areas. It is expected that these “incentivized” economic development zones will attract more growth, particularly commercial development.

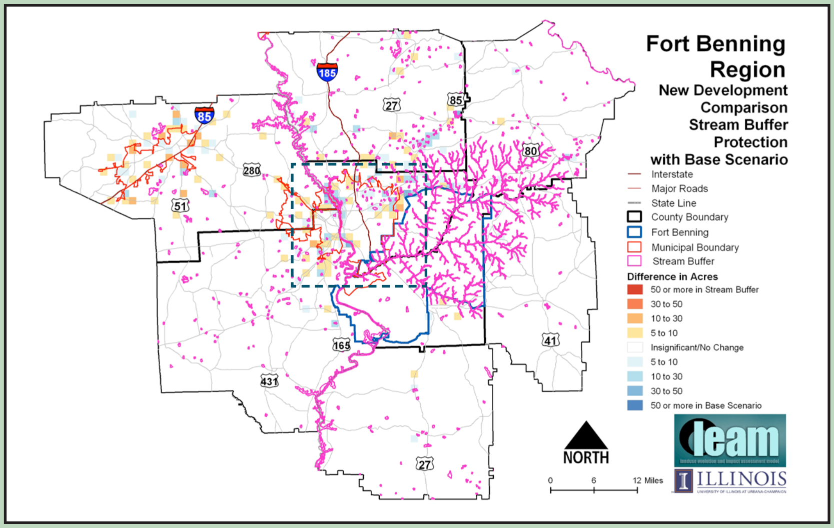
The results show there is much more growth in the industrial park area in eastern Columbus and near the installation under this scenario. However, there is not much more growth in the other industrial park or the marina/museum complex area south of Columbus. Areas with less growth than in the base scenario are scattered around Columbus and the Auburn/Opelika area. Muscogee County is the only county that has significantly more growth, and Lee County has a slight decline in growth relative to the base scenario.

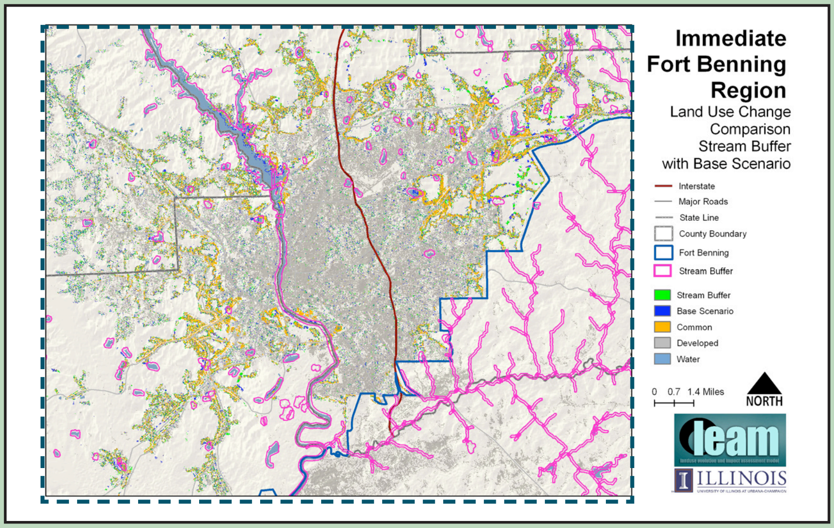




Share of 2000-2030 Urban Growth in Region

	Base	Industrial Parks
Lee	36.7%	36.5%
Muscogee	20.4%	20.9%
Harris	18.6%	18.5%
Russell	14.5%	14.4%
Talbot	3.1%	3.1%
Stewart	2.5%	2.4%
Marion	2.3%	2.2%
Chattahoochee	2.0%	2.0%





Stream Buffer Protection Policy

To the left are images of LEAM simulated future urban growth for a scenario where it is assumed that a policy to protect water quality is established that does not allow development within 60 meters of small streams and 90 meters of large streams. Obviously, this should lessen growth near streams, moving growth to other attractive areas in the region.

The results show that the stream buffer scenario shifts growth away from the streams, particularly along the Chattahoochee River, to other parts of the Columbus area. As a result, there is more growth in Lee County and less in Muscogee and Harris Counties in this scenario relative to the base.

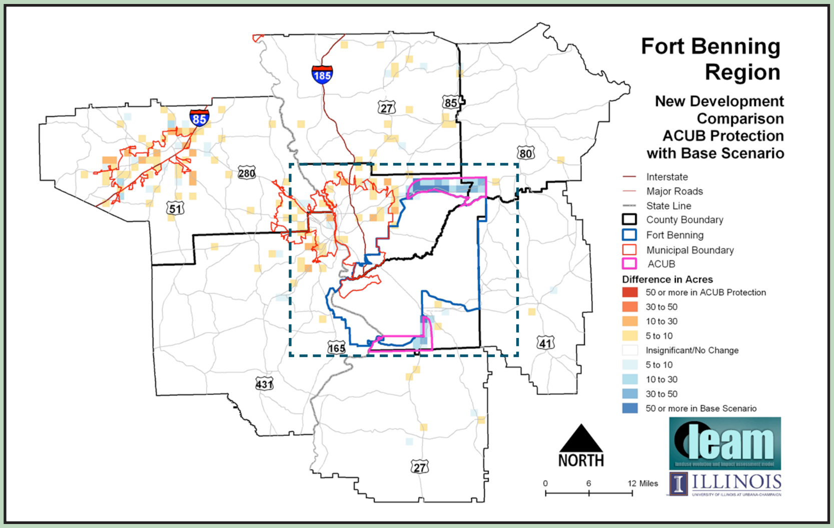
Share of 2000-2030 Urban Growth in Region

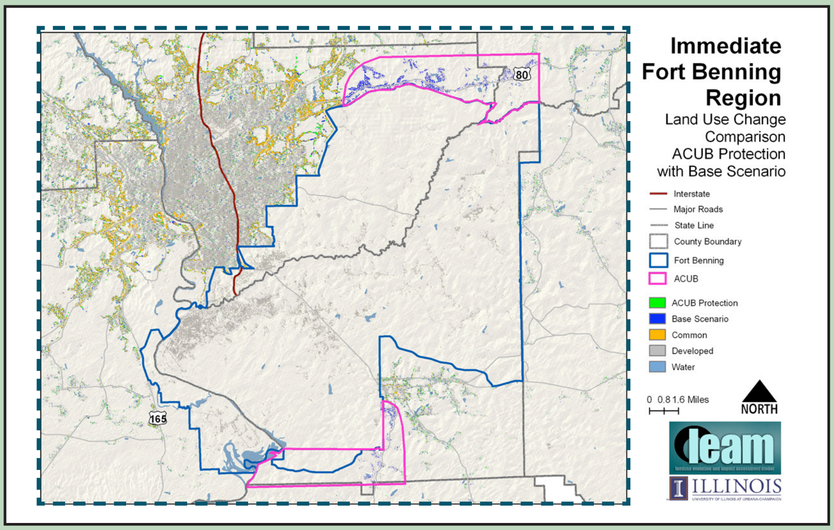
	Base	Stream Buffer
Lee	36.7%	37.2%
Muscogee	20.4%	19.9%
Harris	18.6%	18.4%
Russell	14.5%	14.5%
Talbot	3.1%	3.1%
Stewart	2.5%	2.5%
Marion	2.3%	2.2%
Chattahoochee	2.0%	2.1%

ACUB Protection Policy

To the right are images of LEAM simulated future urban growth for a scenario where it is assumed that a policy is established to protect Army Compatible Use Buffers (ACUB) from development so that they can be used for army training and wildlife habitat. The base scenario projects a significant amount of growth at these buffer areas. Obviously, it is expected that this policy will move growth outside of these buffer areas to other attractive areas in the region.

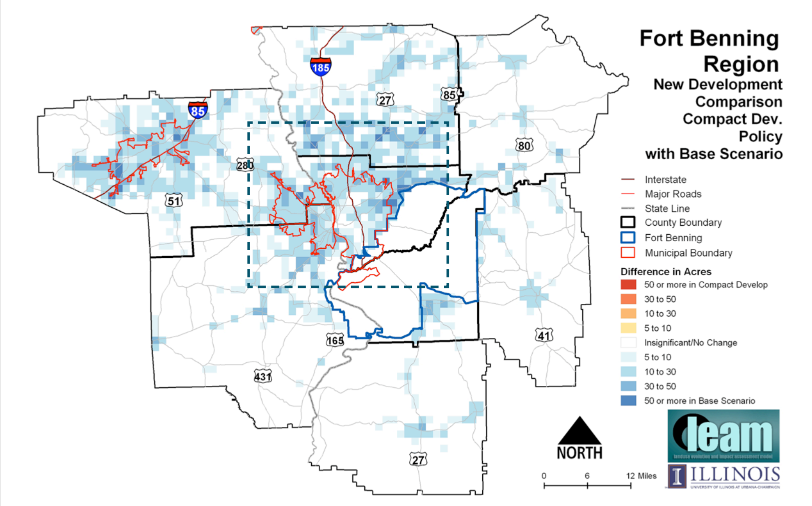
The results show that a large amount of growth does move out from the buffer areas in this scenario, particularly the one along the northern border of the installation, which leads to more growth in the Columbus and Auburn/Opelika area. There is not much growth at areas near the base that are not protected by the buffer, except near the northwest installation boundary. Lee County sees significantly more growth in this scenario relative to the base, as do Harris and Russell Counties; Muscogee County has considerably less growth.

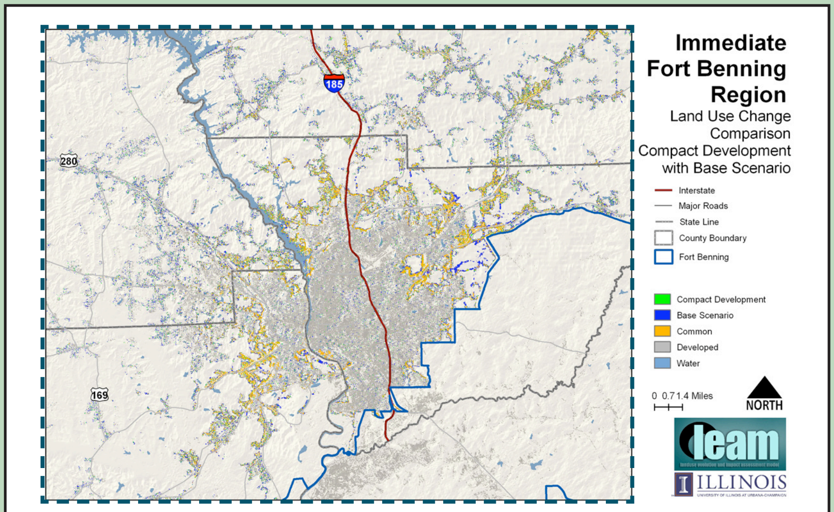




Share of 2000-2030 Urban Growth in Region

	Base	Protect ACUB
Lee	36.7%	37.8%
Muscogee	20.4%	18.8%
Harris	18.6%	19.0%
Russell	14.5%	14.9%
Talbot	3.1%	2.9%
Stewart	2.5%	2.5%
Marion	2.3%	2.3%
Chattahoochee	2.0%	1.8%





Share of 2000-2030 Urban Growth in Region

	Base	Compact Development
Lee	36.7%	37.2%
Muscogee	20.4%	22.9%
Harris	18.6%	17.3%
Russell	14.5%	15.0%
Talbot	3.1%	2.4%
Stewart	2.5%	1.9%
Marion	2.3%	1.6%
Chattahoochee	2.0%	1.6%

Higher Density Development Policy

To the left are images of LEAM simulated future urban growth for a scenario where it is assumed that a policy to encourage higher density development is established, leading to one-third less development acres to meet the needs of the same amount of new households. This policy could encourage smaller lot size, clustered development, and more multi-family housing.

In this scenario, not only is there considerably less growth (one-third) in the region, but there is also a change in where growth occurs. A higher percentage of growth occurs in Muscogee and Russell Counties in this scenario, and less in Lee, Harris, Talbot, and Stewart Counties.

Some Impacts of Future Growth

Effects of Urbanization on Resources

It is important to recognize the impacts future urban growth in the Fort Benning Region will have on the environment, economic and social systems of the region. The assessment of probable impacts is important for understanding the 'so what does it mean' part of the LEAM simulation process.

One impact that can be quickly assessed is the affect on land uses such as agricultural and natural resources. The tables below illustrate how much agricultural, forest land will decline as a result of future growth. In terms of agricultural land, 3% (6,000 acres) will be developed over the next thirty years in the base case, with Muscogee County losing the largest percent of their agricultural land. The only scenario with any significant difference from the base in the loss of agricultural and forest land is the compact development scenario. In this scenario 3,800 less acres of agricultural land is developed.

Forest land makes up the greatest portion of the region's land cover. Under the base scenario, 1.8% (30,000 acres) of the forest land is developed over the next thirty years. Considerably less (10,000 acres less) forest land is developed in the compact development scenario.

Agricultural and Forest Land in the Fort Benning Region

County	Agri. Land Acres in 2000	Baseline % Loss	Compact Dev % Loss	Forest Land Acres in 2000	Baseline % Loss	Compact Dev % Loss
Russell	49,125	1.5%	0.9%	299,114	1.5%	1.0%
Lee	50,607	5.6%	3.5%	297,122	3.6%	2.4%
Talbot	15,880	1.4%	0.7%	207,441	0.5%	0.2%
Stewart	29,416	0.7%	0.4%	225,064	0.3%	0.2%
Muscogee	5,645	13.6%	9.6%	91,143	6.6%	4.9%
Marion	29,548	0.4%	0.2%	165,780	0.4%	0.2%
Harris	23,184	4.9%	3.0%	243,956	2.5%	1.5%
Chattahoochee	2,271	2.1%	0.9%	132,792	0.5%	0.3%
Region	205,676	3.0%	1.8%	1,662,412	1.8%	1.2%

Social Impacts of Future Growth

It is also important to understand the social and economic impacts of future growth. A prototype social impact model was used to examine the potential impacts of future growth on various factors such as local infrastructure cost, automobile travel, energy consumption, and air pollution. These are general estimates, based on average cost data from various national studies, to provide a sense of the potential magnitude of social effects under different future development patterns.

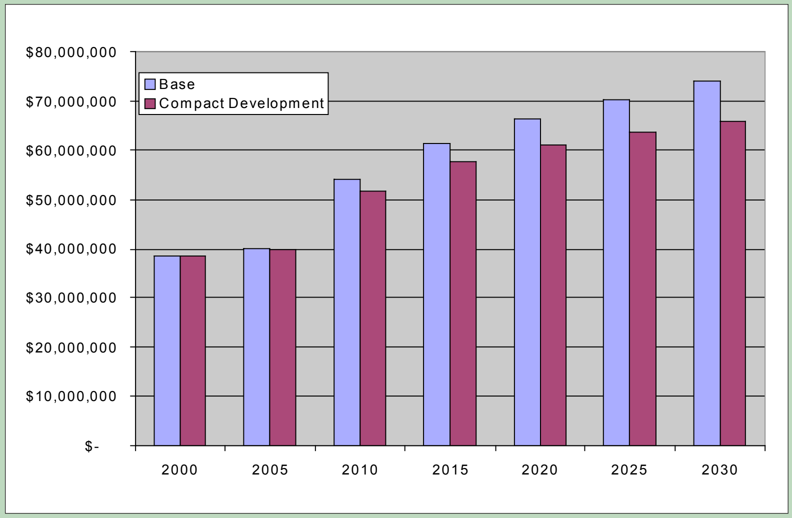
Below is an example of the results of this social impact analysis, showing the impacts of future growth in Harris County for the baseline and compact development scenario. Harris County is a rural county north of Columbus that is expected to see significant growth over the next thirty years, with over 8,700 acres

Local Infrastructure Cost for Residential Development, 2000-

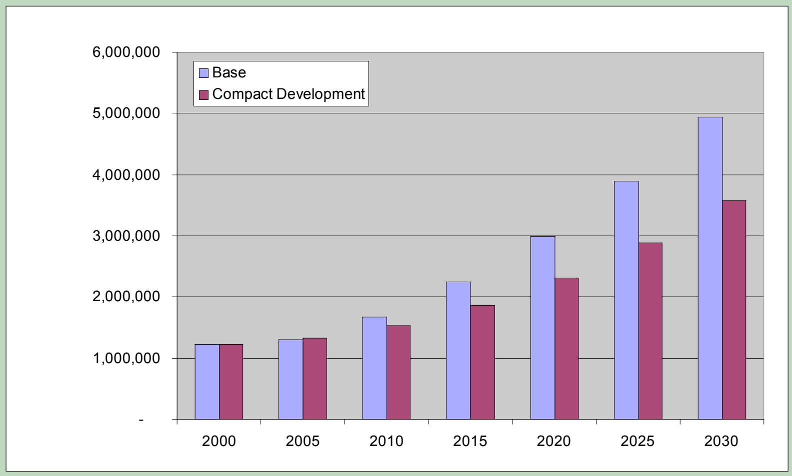
	Base	Compact Development	Percent Difference
Streets	96,587,404	65,701,740	< 32%
Utilities	145,178,438	90,978,931	< 37.3%
Schools	140,636,858	112,920,618	<19.7%

of new development projected in the base scenario and 5,400 acres in the compact development scenario. The compact development scenario was chosen for comparison because this scenario is the most different from the base and, therefore, likely to have the biggest impact on social factors. One would expect that local infrastructure costs, automobile travel, energy consumption, air pollution, and water/sewer demand will be lower in the compact development scenario, given that there is less and more clustered development. The results below support this expectation: local infrastructure costs for residential development are projected to be 20% lower for schools, 37% for utilities, and 32% for roads in the compact development scenario. Vehicle miles traveled are 28% lower by 2030 in the compact development, leading to considerably less air pollution from transportation in the county. Water and sewer demand and energy costs are also projected to be considerably lower with compact development.

Annual Energy Costs



Daily Vehicle Miles Traveled



Air Pollution from Transportation (tons/year)

	Base	Compact Development	Difference
hydrocarbons	334	303	9.2%
carbon monoxide	2,511	2,281	9.2%
nitrogen oxide	214	195	9.1%
sulfur dioxide	18	17	6.6%
particulate matter	14	12	8.8%

Water & Sewer Demand (gallons/day), 2000-2030

	Baseline	Compact Development	% Difference
Water	842,069	721,614	14.3%
Sewer	551,042	477,729	13.3%

These 'so-what' impact assessments are important for comparing simulation outcomes and results. Are we satisfied with these possible results? If not, are there policies that we can enact, or investments that can be made to address these impacts? These and other important questions should be addressed as a consensus of the entire community.

Projecting Future Training

The investment in the creation and development of military installations and associated training and testing facilities is substantial. It is important and cost effective to maintain the benefit of this investment in the future. Growing urban patterns surrounding installations can slowly erode the ability to train/test on the installation. The goal of this effort is to convert predicted and planned urban development patterns into the identification of associated on-installation restrictions.

The ability to erode installation training missions can be evaluated from the perspective of:

- Blast noise and small arms noise
- Generation of dust
- Civilian use of residential and vehicle lights during night training exercises

Fort Benning is facing constraints on mission-related activities due to urban encroachment around its borders. The ever growing presence of civilian concerns puts more and more pressure on the installation trainers to modify military mission activities within the installation boundary. Since Fort Benning is being increasingly pressured to alter training activities, it has become clear there is a need to better define the trend of development, project that trend to the immediate future and identify key opportunities for preserving those lands that are available today to train and test the soldiers of tomorrow. These efforts will most effectively minimize future impacts on its training and readiness mission.

Consider that over the course of the next several years, Fort Benning's training and testing mission will grow as outlined in the recent BRAC (Base Realignment and Closure) announcement. With the relocation of the armor school from Fort Knox, KY, Fort Benning will soon see increased tank training on its ranges. However, over the course of the next several decades, Fort Benning's mission may change to accommodate new or different training requirements, which can create new patterns of disturbance. It is important to the communities around Fort Benning that current regional planning results in a future that continues to attract military activities and the associated regional economic benefits.

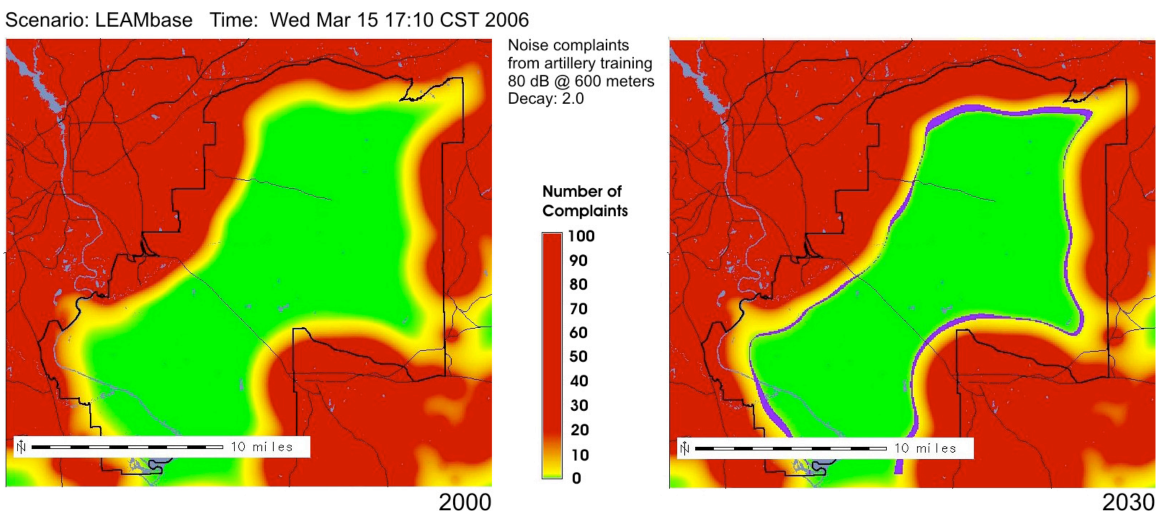
The LEAM land use change analyses have predicted how proposed regional plans might result in future land use patterns, which we can now use to identify training and testing location opportunities within those projected patterns. We accomplish this by virtually placing a training/testing event everywhere in the study area and predicting the probability of community complaints in response to the event. The result is a red-amber-green map showing the probability of community complaint in response to the training/testing event.

These analyses are based on mathematical models that decay noise, dust, and light and measurements of the level of the associated human annoyance. For example, knowing the level of a noise, its decay over space, and its location allows us to generate a map of the level of noise across the landscape. Relating these levels to measurements of human annoyance in response to the noise allows us to convert the noise map to a probability of complaint map. Combining this map with maps of the projected urban patterns results in a community probability of complaint for the given location and volume of the noise source. Recalculating for every location in the study area we get a final map of the probability of community complaint for the given activity anywhere in the study area. For this Fort Benning analysis, the following potential activities are considered:

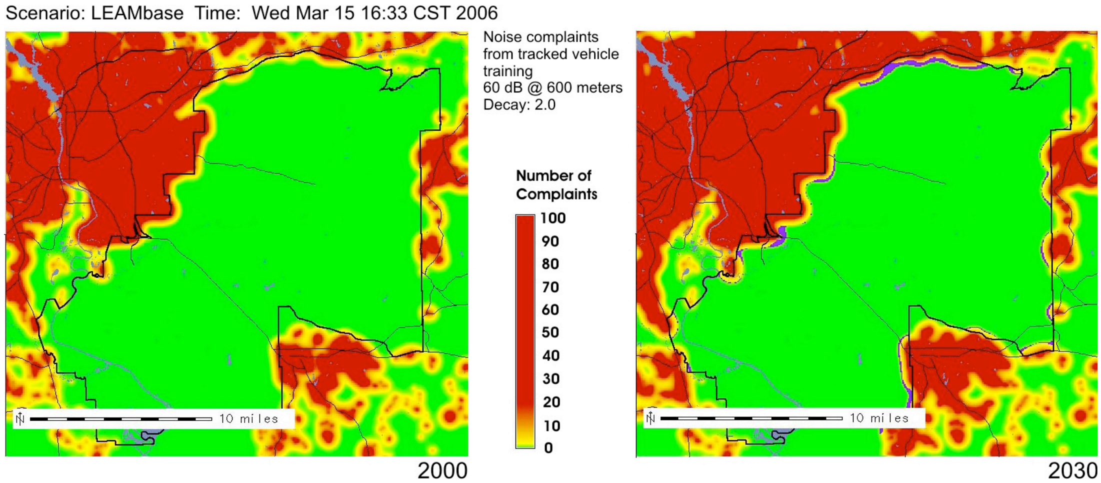
1. Artillery training
2. Tracked vehicle training
3. An aircraft similar to the C-130 training at an altitude of 2,000 meters
4. Helicopter training with the Bell_J_2A at an altitude of 300 meters
5. An F-22 Raptor training at an altitude of 4,500 meters
6. Dust generated by tracked vehicle training
7. Night training requiring dark nights

The flexibility of LEAMtom allows it to be adapted to analyze the potential number of complaints for other and new weapon systems, given some rudimentary data on noise patterns and rates of decay.

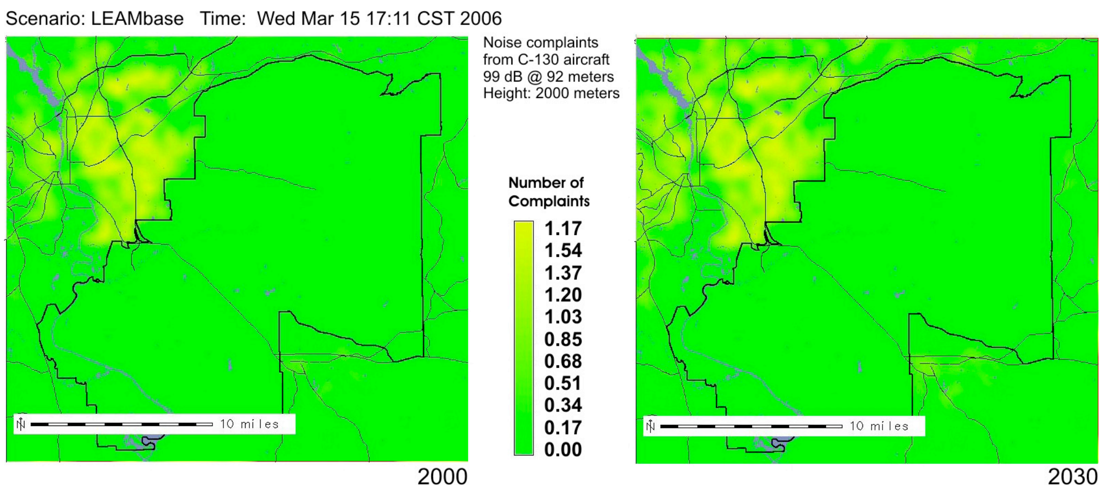
The first five of the current analyses address the tolerance for noise associated with military training by the surrounding residential areas. Every residential location is associated with concentric rings of complaint probability. Training at more distant areas are therefore associated with an increasingly lower number of complaints. Our question, therefore is, “Where, within Fort Benning, can these training activities be carried out after development has occurred with respect to the regional planning scenarios tested by the LEAM lab?” Each location on the map is then given a probability of complaint associated with every other residential area across the entire map, and these values are combined to give an overall probability of complaint. In the following set of maps, military training in the green areas is projected to generate less than two complaints, yellow is about 10 complaints, and red 20 or more complaints from a given event.



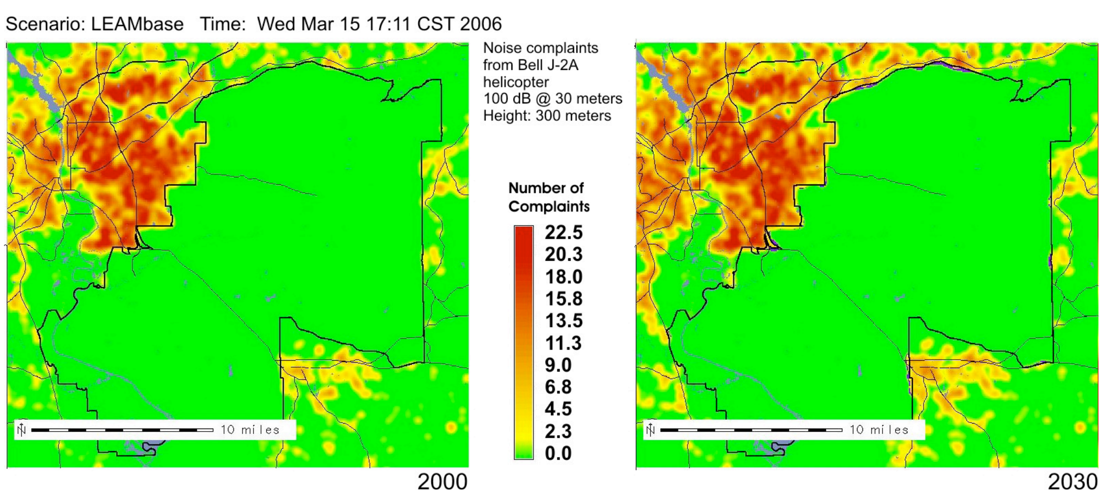
The pair of maps above represents the number of noise complaints for an artillery training exercise BEFORE and AFTER growth. This event would generate noise measured at 80dB at a range of 600 meters. Notice that a significant portion of land deemed “safe” for artillery training purposes exists beyond the boundary of the installation. These are the large green areas extending beyond the boundary to the south. These contours do not represent lands that should be used for training purposes, but rather lands that could be used if they were available (LEAMtom does not consider the installation boundary when assessing “safe” areas on which the Army can train, therefore the entire study area is open to its interpretation). There is little to no development here and few neighbors to potentially be bothered by training activities. It should be noted that this “safe” area shrinks as the scenario runs to completion, so that by the final time step, sufficient development has occurred to eliminate some of this land as potential training land (areas in purple).



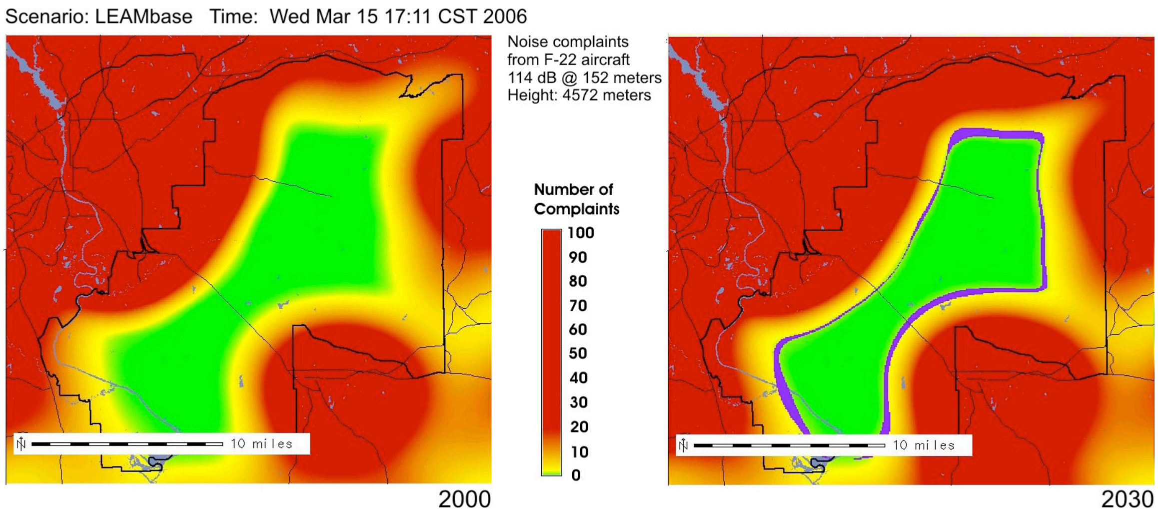
These maps were generated by LEAMtom and show the number of complaints from surrounding residential areas BEFORE and AFTER growth in response to a tracked vehicle training exercise generating noise measured at: 60 dB @ 600 meters.



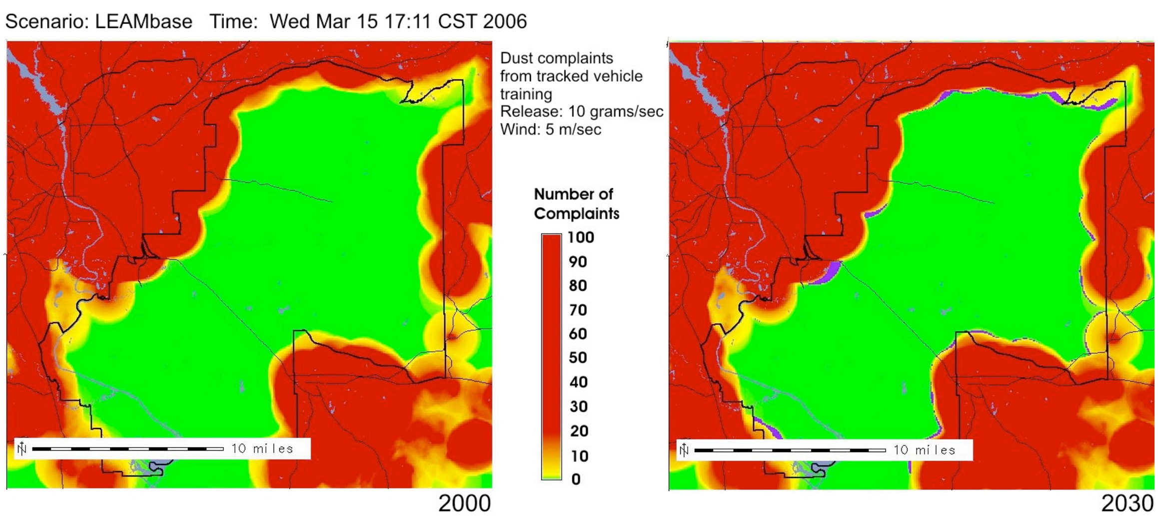
These maps show the complaint probability from surrounding residential areas BEFORE and AFTER growth, in response to a C-130 at an altitude of 2,000 meters generating noise measured at: 99 dB @ 92 meters.



These maps show the complaint probability from surrounding residential areas AFTER GROWTH in response to a Bell Jet Ranger helicopter at an altitude of 300 meters generating noise measured at: 100 dB @ 30 meters.



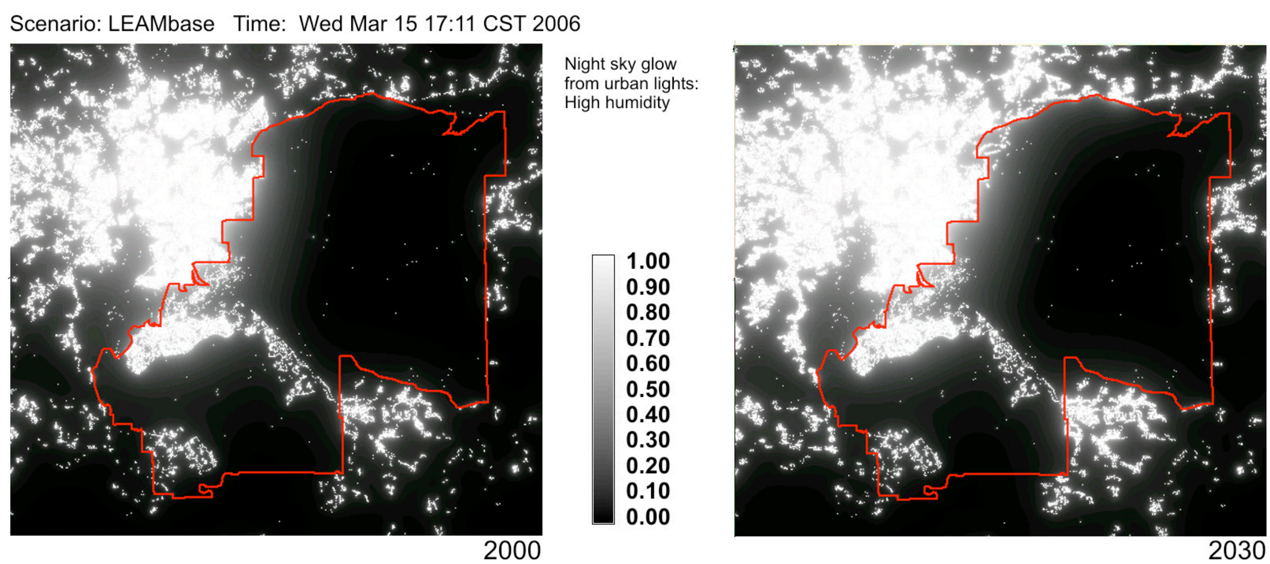
LEAMtom can predict the number of complaints from an Air Force F-22 Raptor flying at an altitude of 4,572 meters. This aircraft can generate a noise measured at 114 dB at 152 meters. This is a significant amount of disturbance and even at this altitude, the land with a low probability of complaint shrinks accordingly by the time the simulation runs to completion.



In addition to complaints about noise, LEAMtom can also predict the number of complaints resulting from the dust generated by tracked vehicle training. Currently, dust is modeled at a release rate of 10 grams per second, and is carried on the wind at 5 meters per second.

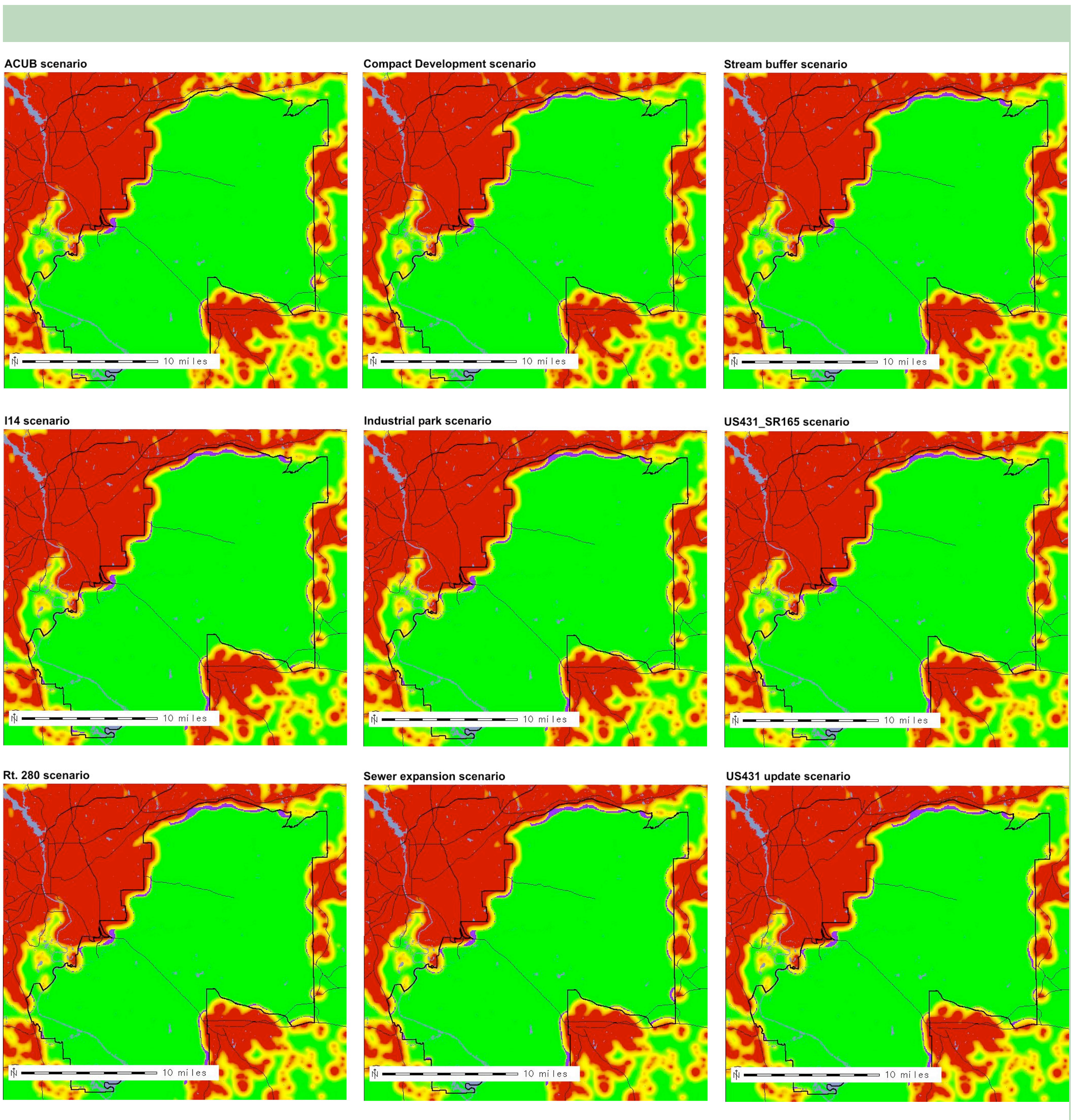
Where the first six LEAMtom analyses listed above examine the probability of civilian complaints due to the army's effect on the community, the seventh looks at the effect the surrounding communities have on the army and its capacity to conduct night training. The ability to the nighttime battlefield with night vision goggles can be greatly compromised with the bright city lights associated with residential and commercial areas. The sky glow associated with these lights, high humidity, and low cloud decks can render large areas unsuitable for night training.

LEAMtom can predict where this is likely to be a problem by simulating the night sky glow associated with civilian light pollution. To generate artificial sky-glow maps, each residential and commercial location is allowed to brighten the sky at every other location in the area. Combining all of the sky-glow calculations at every location as a result of the surrounding urban areas yields a brightness index.



These maps show the relative potential for night training exercises BEFORE and AFTER growth in response to residential lights reflecting off clouds along with high atmospheric humidity. Note the somewhat decreased areas of blackness in the map on the right (future training opportunities) versus the map on the left (current training opportunities). It is within these areas of darkness that the military can effectively conduct night time training activities without interference from residential light pollution.

The following groups of maps examines the differences in probability of complaint against a tracked vehicle training exercise for all the simulated scenarios. The maps displayed below represent the last time step in each simulation, or what the region might look like in terms of the number of complaints in the year 2030. Note that visually, all the maps for this training event look identical at this resolution. Only on a fine-scale graphical analysis can the differences be detected between the images. For this reason, we chose not to include the final time step maps for the other training exercises. The next section of this report summarizes a more in depth analysis of these training exercises for each of the simulations that were performed.



Summarizing the Scenarios

An analysis of the maps resulting from each scenario was performed to see how future growth might affect Fort Benning. And while it is not possible to predict exactly which locations will become urbanized, it is feasible to predict which locations are the most attractive to urbanization, and thus how much this growth will affect training within the installation. The question then becomes, "How attractive is the land near Fort Benning to development? And how will this attractiveness translate to training area loss due to land use conflicts?"

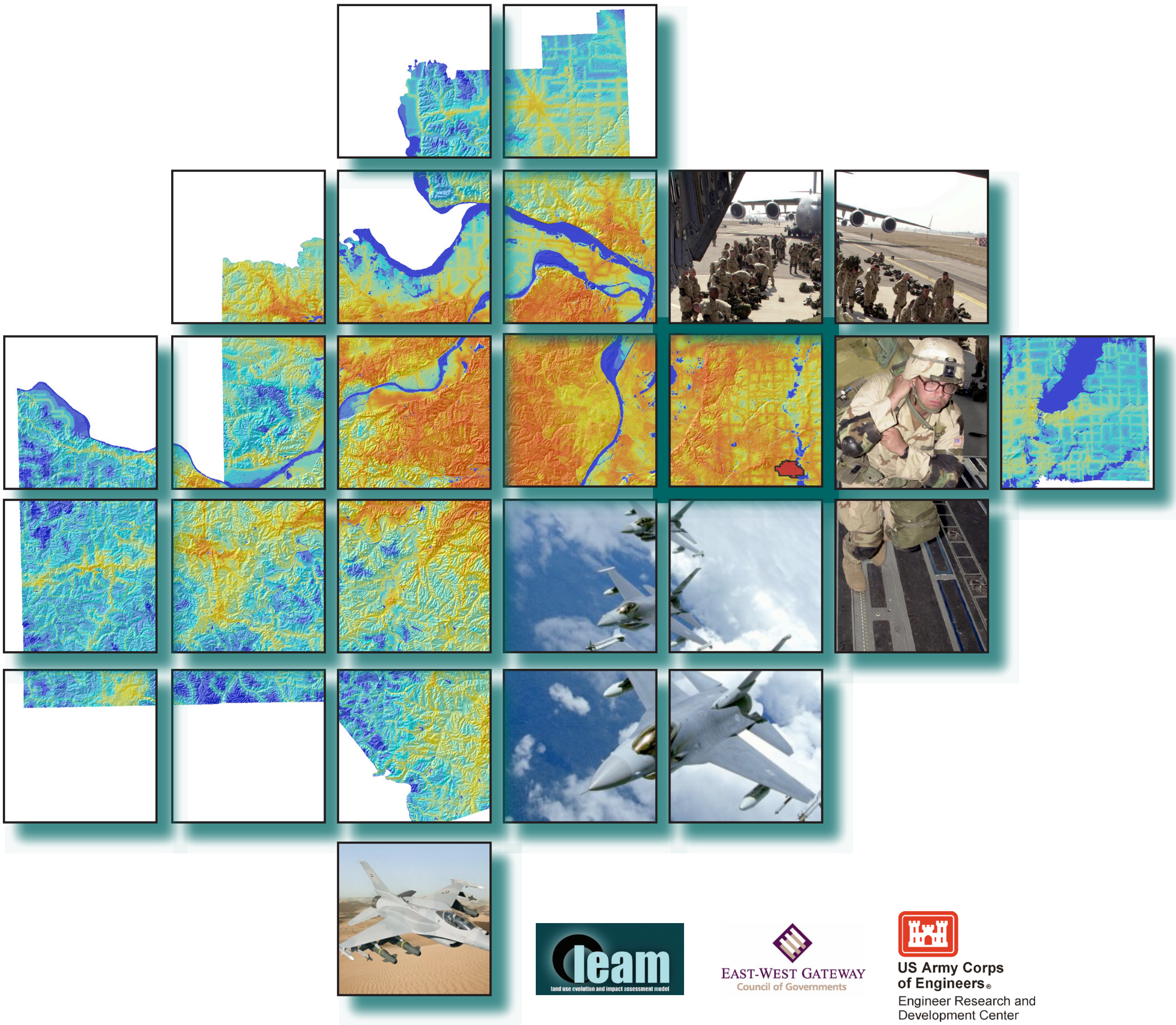
The following table outlines the potential loss of lands used for training within the boundaries of Fort Benning (in hectares) by training disturbance and land use scenario.

Training Disturbance	Tracked Vehicle Training Noise	Artillery Training Noise	C-130 Aircraft Noise	F-22 Aircraft Noise	Bell J-2A Helicopter Noise
current training land available (ha)	69714	43151	73844	25234	73357
Scenario	**Change in hectares of potential training land by 2030**				
Base scenario	-4016	-7213	-13	-6562	-453
I14 around	-4151	-7459	-13	-6795	-435
I14 thru	-4044	-7159	-12	-6465	-422
US431 expansion	-3992	-7185	-14	-6544	-453
431-165 connector	-3956	-7136	-13	-6506	-442
ACUB	-2074	-4501	-13	-4788	-380
New industry	-4016	-7213	-13	-6562	-453
New utilities	-4117	-7434	-13	-6994	-456

Training Disturbance	Tracked Vehicle Training Noise	Artillery Training Noise	C-130 Aircraft Noise	F-22 Aircraft Noise	Bell J-2A Helicopter Noise
Scenario	**Potential Training Area loss (%)**				
Base scenario	-5.8%	-16.7%	0.0%	-26.0%	-0.6%
I14 around	-6.0%	-17.3%	0.0%	-26.9%	-0.6%
I14 thru	-5.7%	-16.6%	0.0%	-25.6%	-0.6%
US431 expansion	-5.7%	-16.7%	0.0%	-25.9%	-0.6%
431-165 connector	-5.7%	-16.5%	0.0%	-25.8%	-0.6%
ACUB	-3.0%	-10.4%	0.0%	-19.0%	-0.5%
New industry	-5.8%	-16.7%	0.0%	-26.0%	-0.6%
New utilities	-5.9%	-17.2%	0.0%	-27.7%	-0.6%

Scott Air Force Base

Results of LEAM Simulations



leam
land use evolution and impact assessment model

East-West Gateway
Council of Governments

US Army Corps of Engineers®
Engineer Research and Development Center

January 2006

Scott Air Force Base Results of LEAM Simulations

January 2006

This project is cooperatively executed by

University of Illinois
LEAM Laboratory

US Army Engineer Research and Development Center
Construction Engineering Research Laboratory

East West Gateway
Council of Governments

Support is provided by the Strategic Environmental Research and Development Program, the Department of Defense's corporate environmental research and development program, in partnership with the Department of Energy and the Environmental Protection Agency. In keeping with the Department of Defense's interests in maintaining military readiness for national defense, SERDP is committed to creating sustainable military communities.

LEAM development and applications are conducted and managed by a team of faculty, staff, and students from the University of Illinois at Urbana-Champaign.

LEAM brings together expertise in substantive issues, modeling, high-performance computing, and visualization from the departments of Urban and Regional Planning, Geography, Economics, Natural Resources and Environmental Sciences, Landscape Architecture, Civil Engineering, the National Center for Supercomputing Applications (NCSA), ERDC Construction Engineering Research Laboatory, and private industry.

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The first Regional Planning Workshop that co-joins the planning efforts of Scott Air Force Base and its surrounding St Clair County communities took place in November of 2005. Its stated purpose was to provide key stakeholders an opportunity to consider the potential economic development of the area and its effects (present and future) on Scott Air Force Base. The workshop is considered an on-going effort sponsored by East-West Gateway Council of Governments, the University of Illinois Department of Urban and Regional Planning LEAM Laboratory, and the Army Corps of Engineers Engineer Research and Development Center (ERDC-CERL). To date, twenty participants representing local planners, economic development interests, local government officials, Illinois state agency representatives, and Scott AFB planners and engineers, have taken part in the effort.

This report outlines the resulting scenario modeling and analysis as suggested by the stakeholder group. It follows two previous documents, an initial Charrette Report (Novemeber 2005) and a Charrette Results Report (December 2005).

The main analysis tool utilized is the Landuse Evolution and impact Assessment Model (LEAM), and the LEAM suite of tools. LEAM helps describe the future implications of current planning decisions. It has been developed to help coordinate complex regional planning activities by providing local stakeholders the ability to examine the future implications of current local policies and investments. LEAMtom (LEAM Training Opportunities Model) was used extensively in this work to assess how future land use change may restrict military training and other mission related activities on an installation.

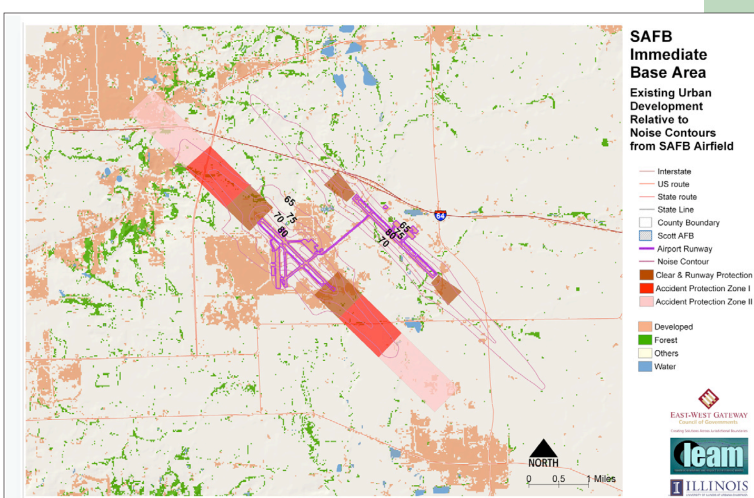
A ‘base case’ scenario and six alternative scenarios were modeled and analyzed for this work. The scenarios, listed below, were selected based on the preferences expressed by workshop participants.

The following describes the results of the scenarios using LEAM and LEAMtom to illustrate how the proposed investments and policies may affect landuse change and subsequent training opportunities at the installation over the next thirty years.

We hope this work continues to help facilitate regional thinking in the Scott AFB region. We hope this effort has provided (and will continue to provide) a greater understanding of the potential economic development of the region and its implications on land-use, and Scott AFB. It is our hope that this preliminary effort will continue and lead to more formal joint landuse operations in the region.

LEAM Simulations

1. Business as Usual or Base
2. Expansion of MidAmerica
3. Scott AFB 50% Plusup
4. New I-64 Interchange
5. Commercial Growth Zones
6. Gateway Connector
7. Brownfield Redevelopment



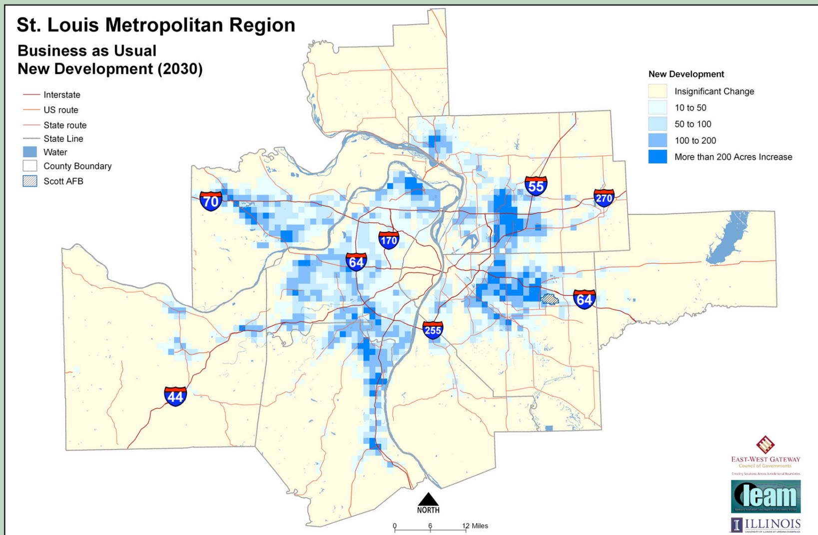
Business as Usual or Base

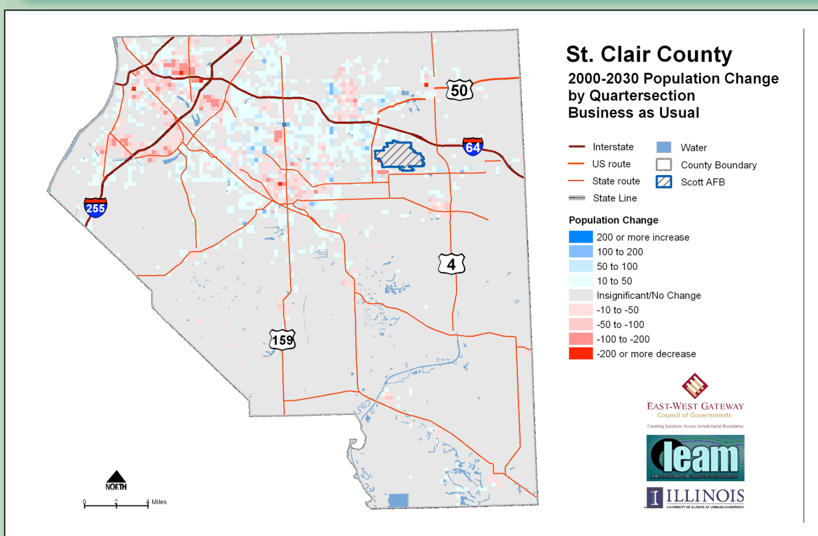
To the right are images of LEAM simulated future urban growth. The simulation uses the set of drivers used in the blueprint LEAM model and assumes 'business-as usual' – economic and demographic trends continue as they have in the recent past. In this scenario, population is projected to increase by 78,000 over the next thirty years.

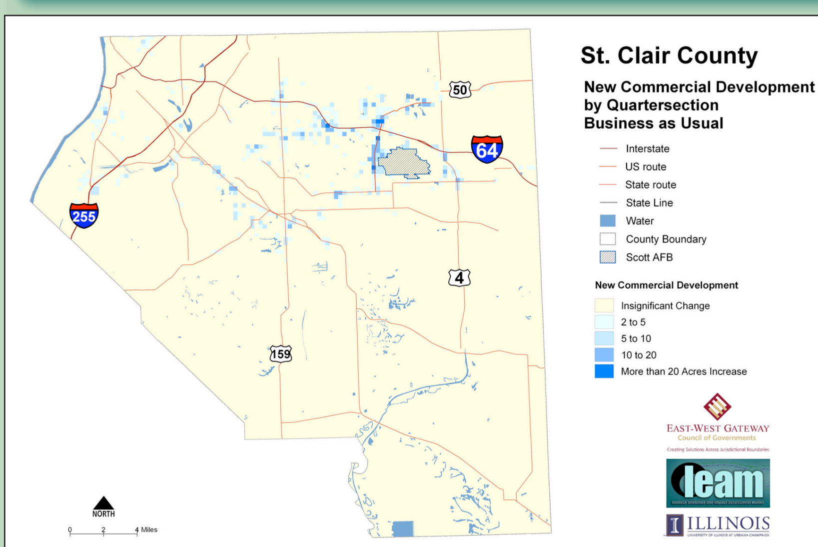
Two adjustments were made to this scenario from the one presented in November: probability of residential development was increased for an area west of O'Fallon (area is platted for residential) and the Frank Scott Parkway was added to the transportation network.

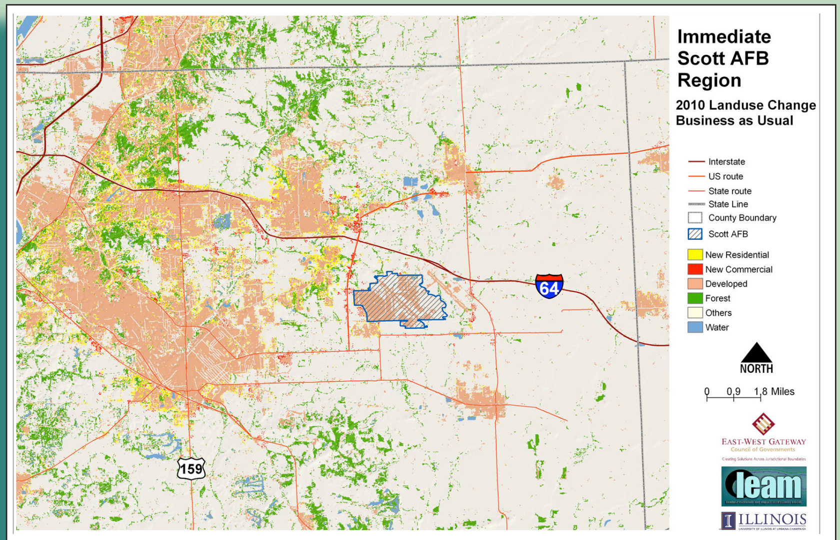
The first map shows new development projected to occur in the St. Louis region over the next thirty years. The middle figure is a map of St. Clair County population growth and the bottom figure is a map of new commercial development in the county.

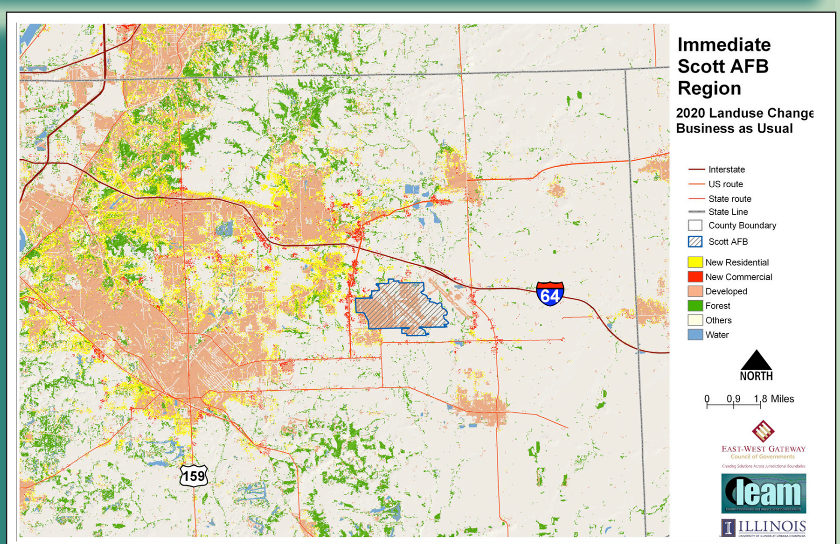
Regionally there is significant growth that occurs northwest of St. Louis (St. Charles County), south of St. Louis (Jefferson County);, and there is a large amount of growth in Illinois (43% of the total regional growth).

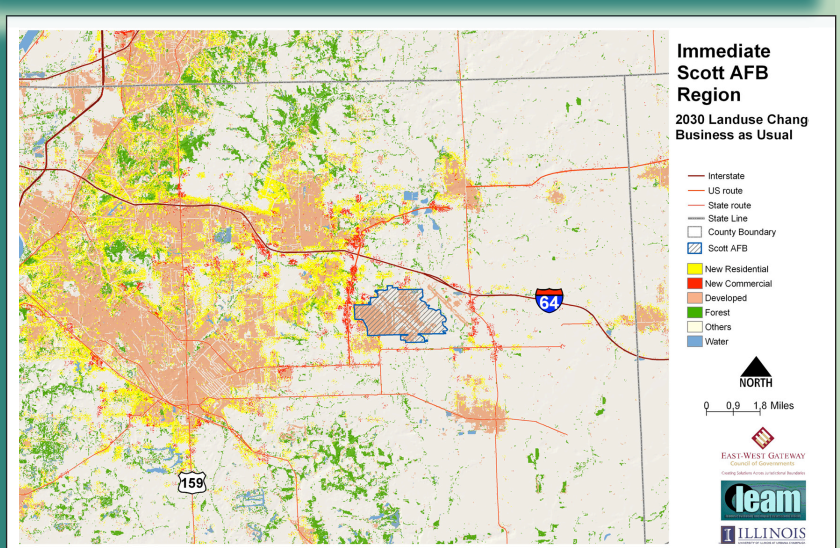












To the left are images that show LEAM simulated urban growth in the Scott AFB region over time - 2010, 2020, 2030.

Note the strip commercial development along the main arterials near Scott AFB, and the commercial development at Mid America Airport.. There is also considerable residential development in O'Fallon, Shiloh, and Belleville.

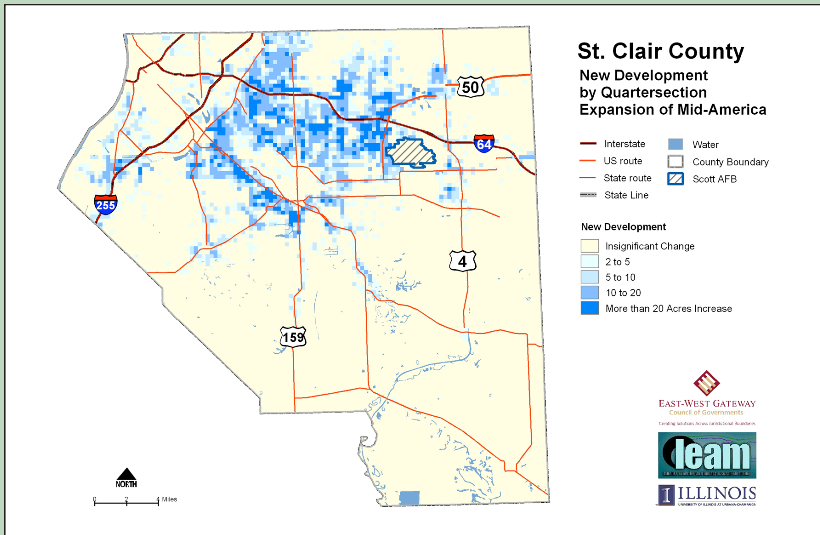
Expansion of MidAmerica

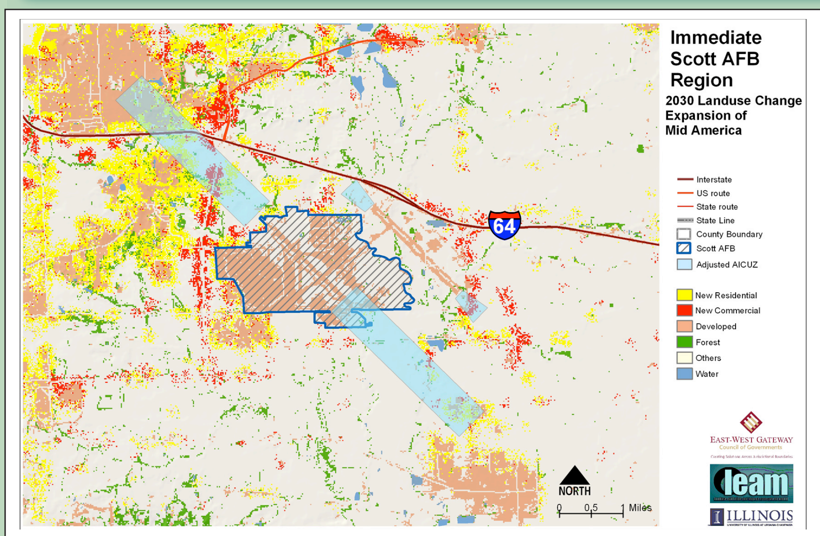
To the right are images of LEAM simulated future urban growth for a scenario where MidAmerica is expanded and the airport becomes a major employer in the region.

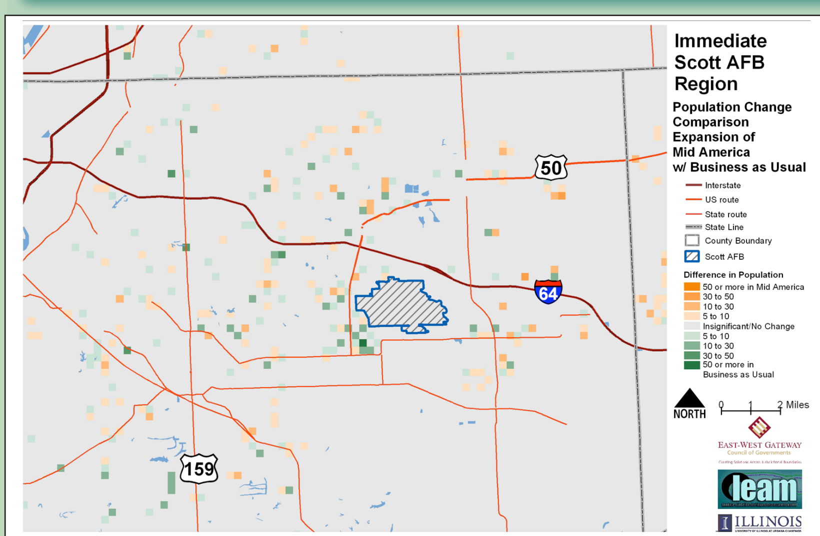
The first map shows new development in St. Clair County for this scenario (darker blue indicates more growth.)

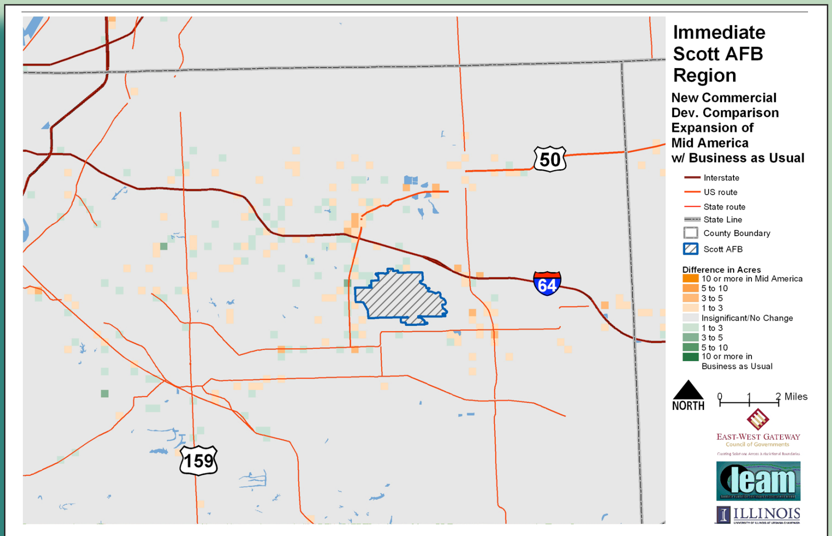
The middle figure is a map of growth in the immediate Scott AFB region, showing residential (yellow) and commercial (red) land use change by the year 2030.

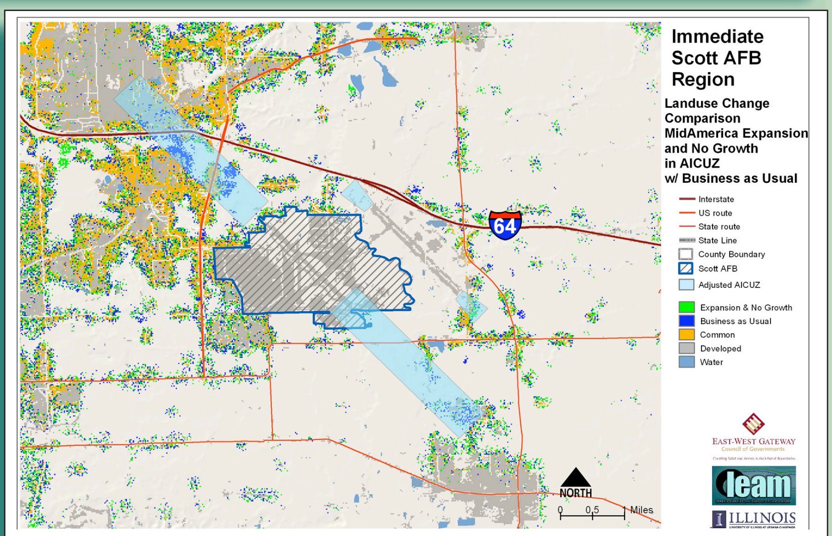
The bottom figure compares population change by quarter-section in the MidAmerica expansion scenario with the base. Orange indicates where population increases more in the MidAmerica expansion scenario. Green is where population increases more in the base.

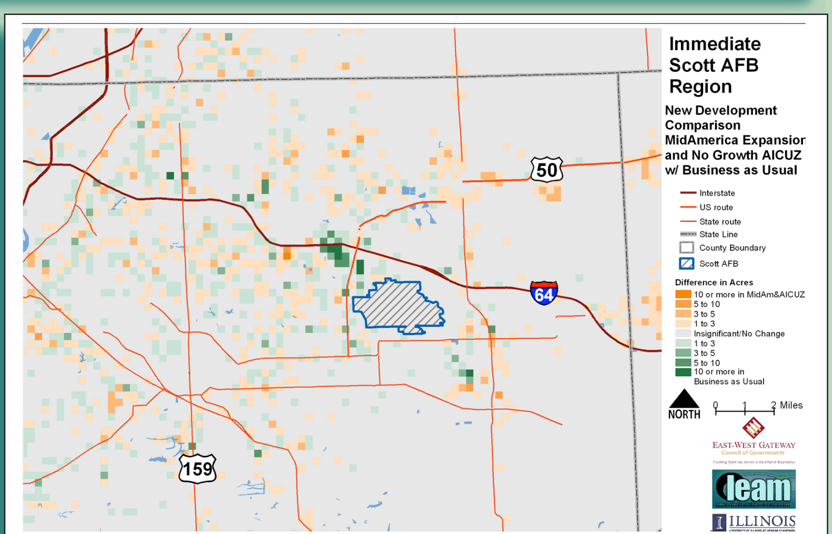












The top left map compares new commercial development in the MidAmerica expansion scenario with the base.

We also did a run of the MidAmerica Expansion scenario assuming a no-growth policy for the AICUZ. The AICUZ area was adjusted for this scenario: it is extended 2000 feet to the northwest because it is assumed that significant expansion of the airport will precipitate the need to extend the installation runway.

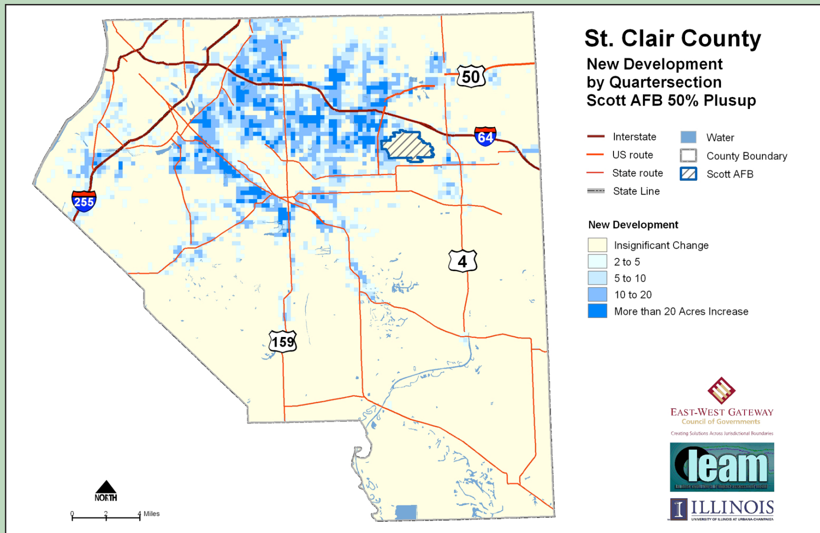
The middle figure compares the land use results of the Scott Plusup with no growth in the AICUZ to the base scenario.

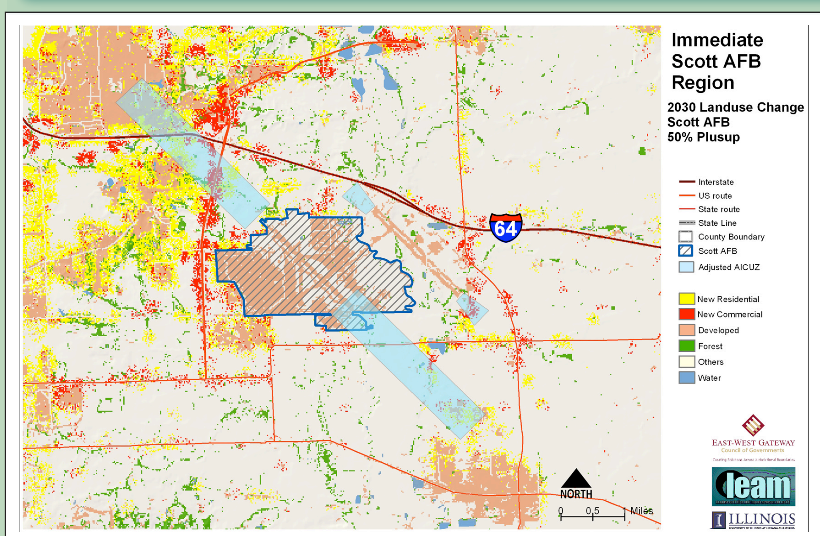
The bottom figure compares the amount of new development (by quarter-section) of the Scott Plusup scenario with the AICUZ no growth policy to the base scenario.

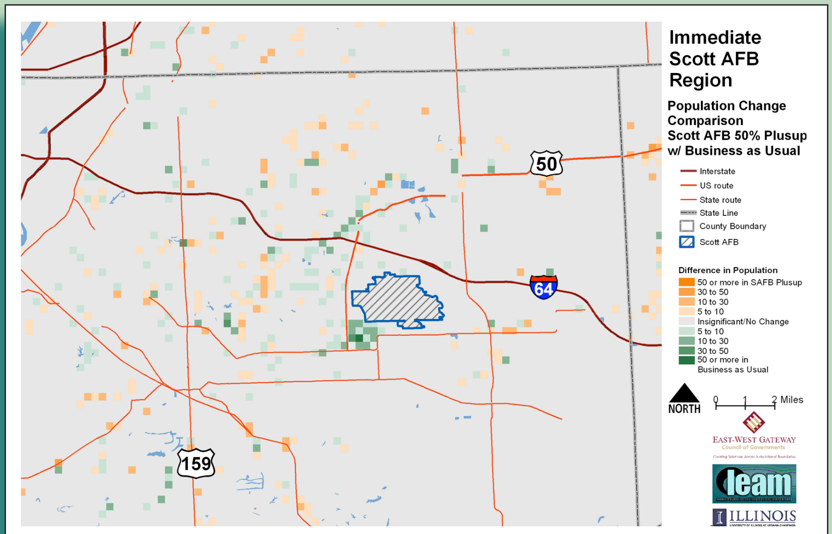
Scott AFB 50% Plusup

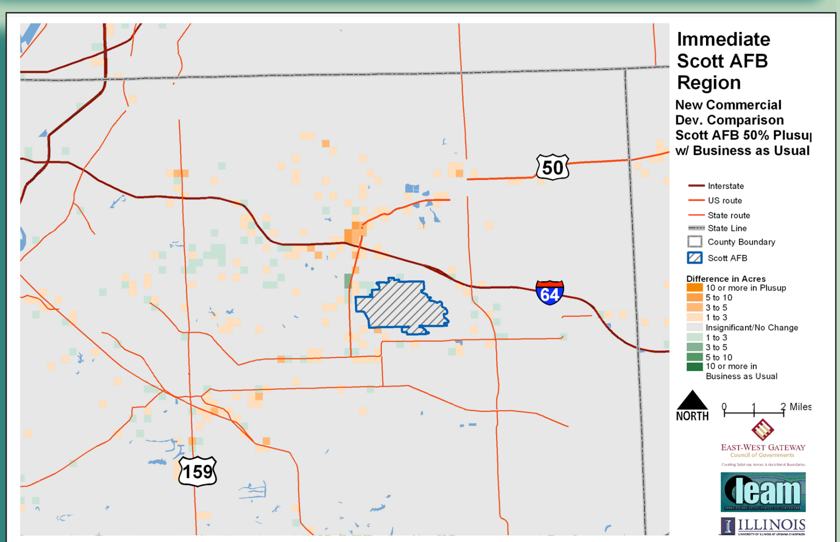
To the right are images of LEAM simulated future urban growth for a scenario where military personnel at Scott AFB increases by 50% (7,000 additional troops).

The first map shows new development for St. Clair County for this scenario. The second figure is a map of growth in the Scott AFB region, showing residential (yellow) and commercial (red) land use change by the year 2030.









These maps show that an increase in personnel at the base will not lead to significant changes in growth patterns in the region.

The first figure is a map comparing 2030 population change. (by quartersection) for the Scott AFB 50% Plusup scenario with the base. Orange indicates where population increases more in the Plusup scenario and green is where population increases more in the base scenario.

The second figure compares new commercial development in the Scott Plusup scenario with the base. Commercial development increases more to the northwest of the base in this scenario.

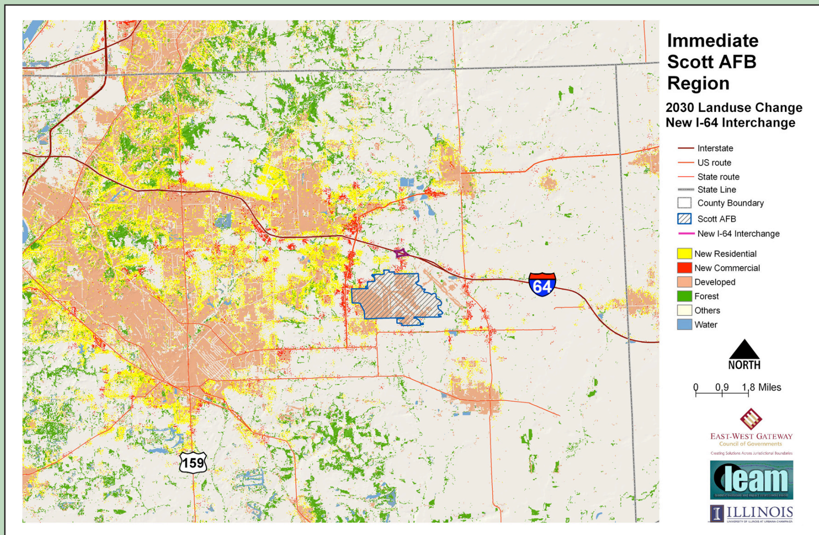
New I-64 Interchange

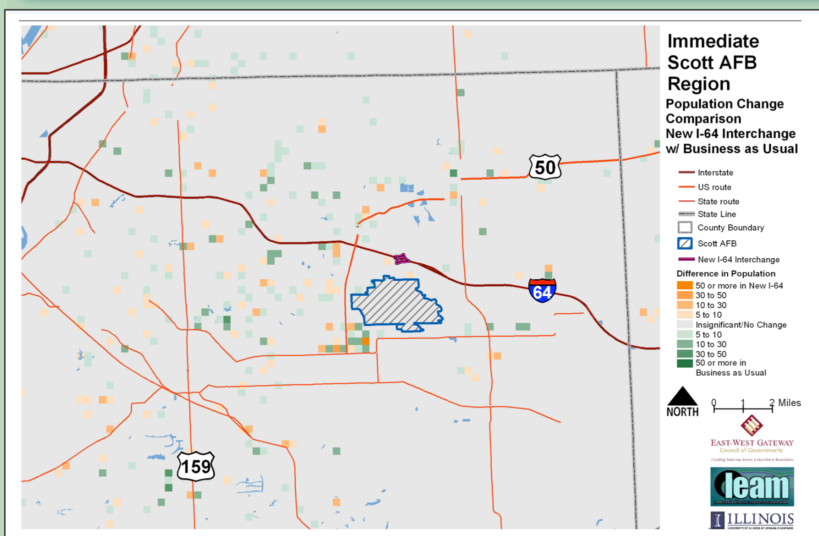
To the right are images of LEAM simulated future urban growth for a scenario where a new interchange is built on I-64 just north of Scott AFB.

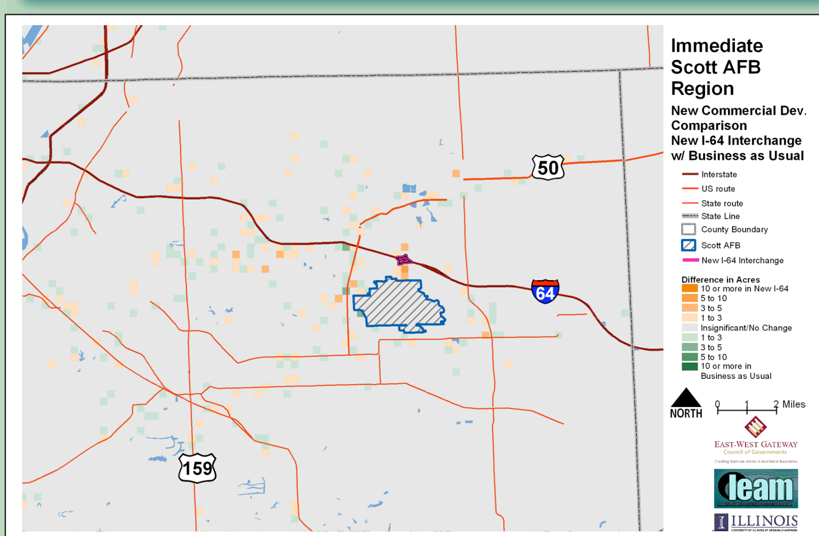
The maps indicate that there is not a signficant change in growth patterns as a results of adding the interchange, other than an increase in commercial development near the interchange. The first map shows land use change in the Scott AFB region under this scenario (yellow indicates new residential growth and red is new commercial growth).

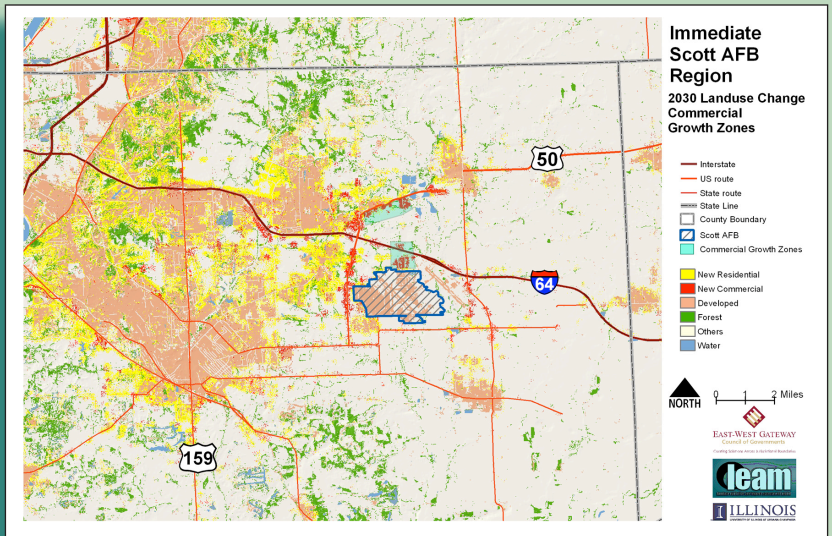
The middle figure is a map comparing population change (by quarter-section) from the New I-64 interchange scenario with the base. Orange indicates where population increases more in the new interchange scenario and green is where population increases more in the base scenario.

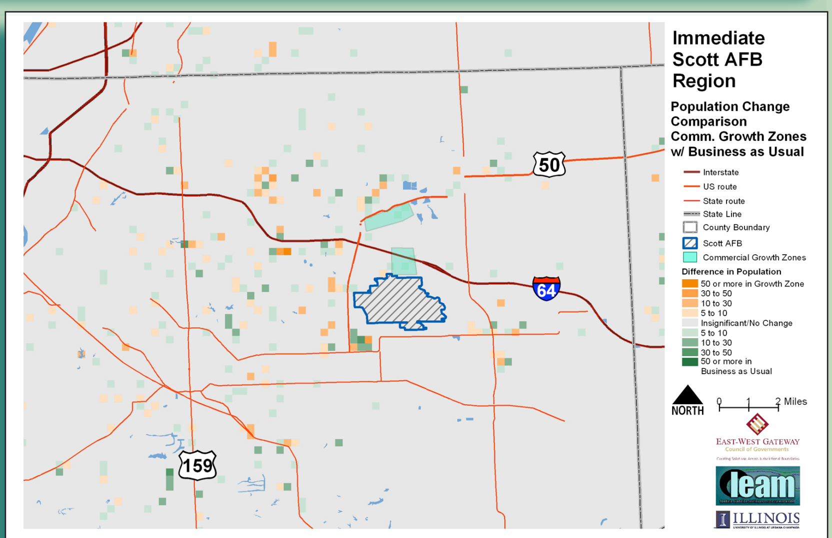
The bottom figure is a map comparing new commercial development in the New I-64 interchange scenario with the base. This map does show an increase in commercial development just north of the base where the interchange is located.

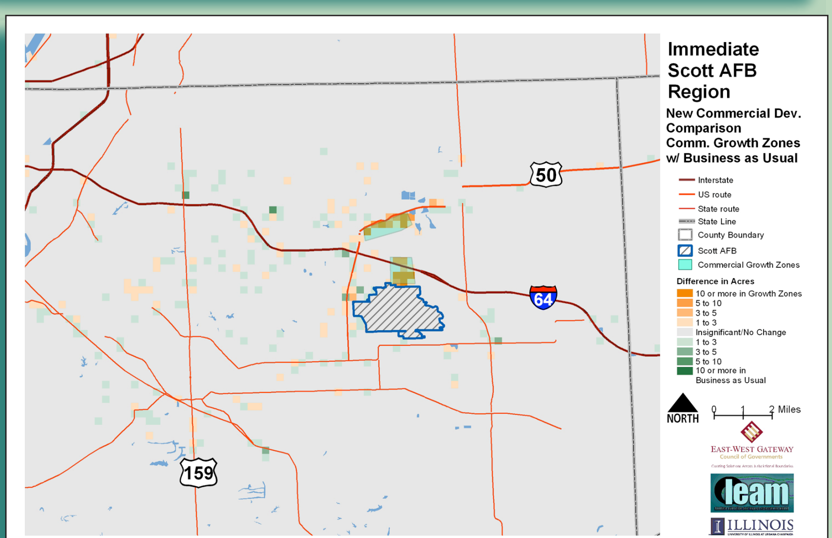












Commercial Growth Zones

To the left are images of LEAM simulated future urban growth for a scenario that assumes two commercial/industrial parks have a higher likelihood of developing (given the infrastructure and current zoning). In this scenario the only noticeable change is the increase in commercial development in the commercial zone areas.

The first map shows land use change for the Scott AFB region under this scenario (yellow indicates new residential, red is new commercial growth).

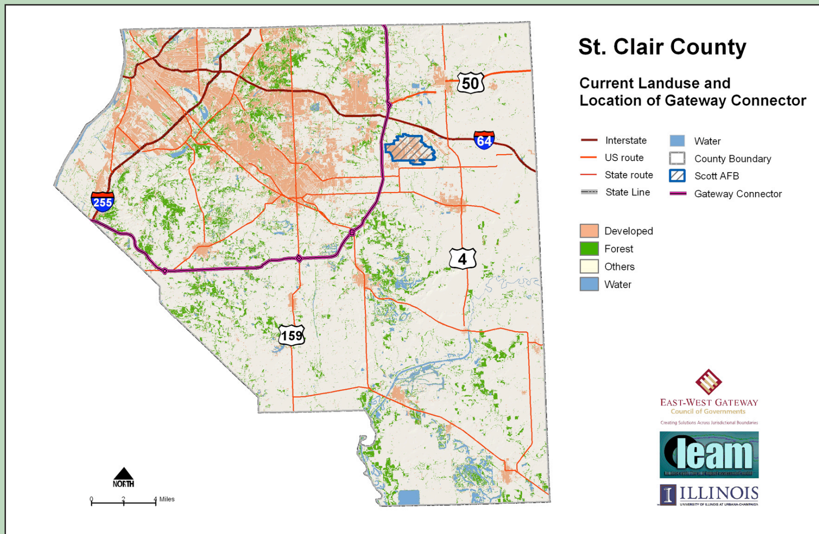
The middle figure is a map comparing population change (by quarter-section) from the Commercial Growth Zone scenario with the base. Orange indicates where population increases more in the commercial growth zones scenario and green is where population increases more in the base scenario.

The bottom figure is a map comparing new commercial development in the Commercial Growth Zone scenario with the base.

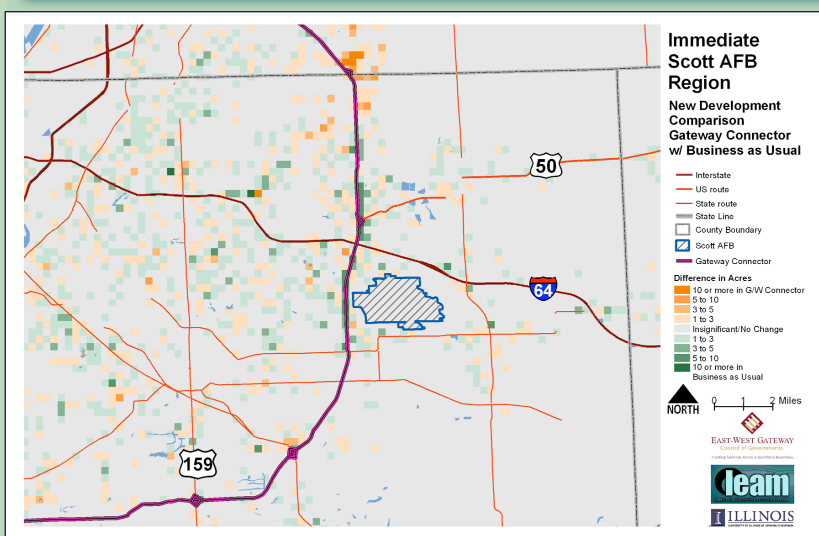
Gateway Connector

To the right are images of LEAM simulated future urban growth for a scenario where the Gateway Connector, a new interstate that goes through St. Clair County, is built.

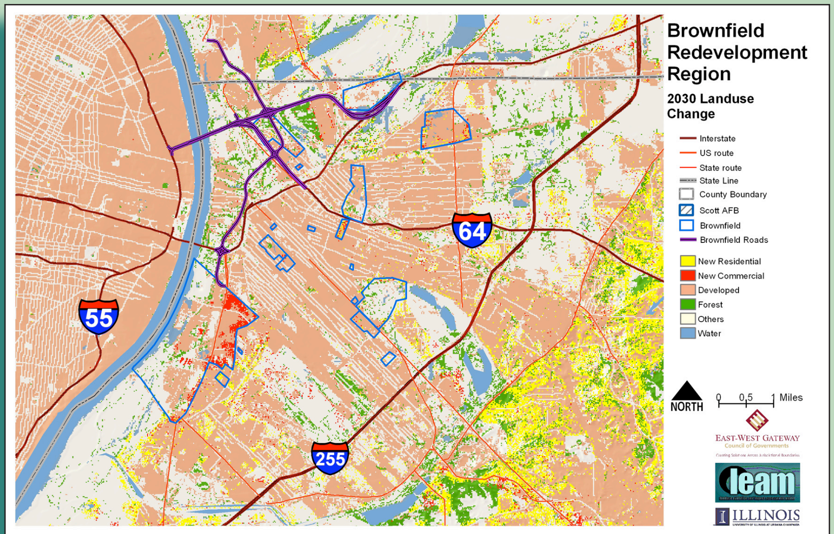
The first map shows current urban land use in St. Clair County, with the location of the potential Gateway Connector.

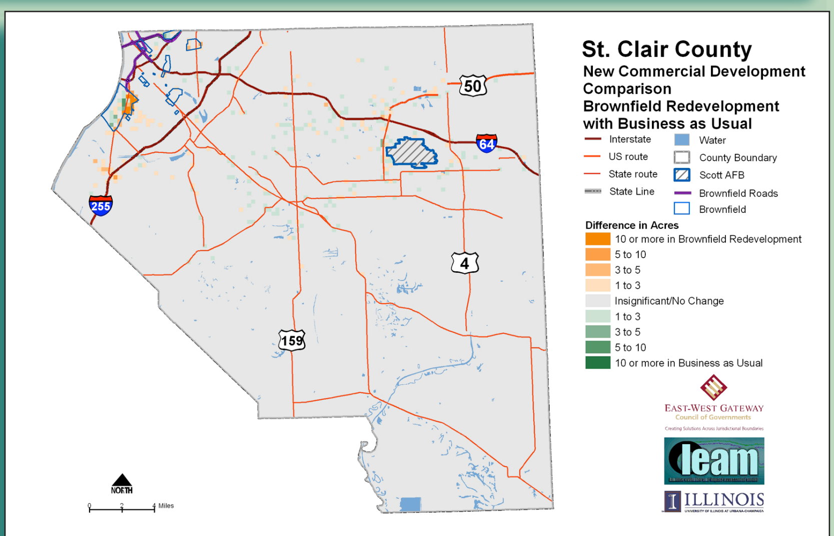


The second figure is a map comparing new development in the Gateway Connector scenario with the base. This map indicates that, under the Gateway Connector scenario, significantly more growth is projected to occur at the new ramp near the St.Clair/Madison County line and a small increase in growth is expected at one of the new ramps in the southern part of the county. There is less growth along the Gateway Connector near the base because commercial development will not occur along the road once it becomes an interstate.



Brownfield Redevelopment





To the right are images of LEAM simulated future urban growth for a scenario where brownfields in the East St. Louis region are available for redevelopment and road improvements for Route 3 and East Missouri Avenue, and a new bridge. connecting I-55 and I-70 are completed.

The first figure shows land use change for the immediate brownfield redevelopment area (East St. Louis). This map shows redevelopment starting to occur in the brownfield areas over the next thirty years. The second map compares new commercial development (by quarter-section) in the Brownfield Redevelopment scenario with the base.

Projecting Future Training Opportunities

The long-term value of an installation is based on its ability to accommodate both current and potential future missions. Scott AFB currently has a mission that has little impact on surrounding communities except for land under the landing and take-off areas at either ends of its and Mid-America's runway. Primary long-term mission analysis focuses on the absolute requirement to maintain the functionality of the runway – the primary asset of any airfield. Secondly, expansion of the airfield through runway lengthening and/or addition of more runways must be considered.

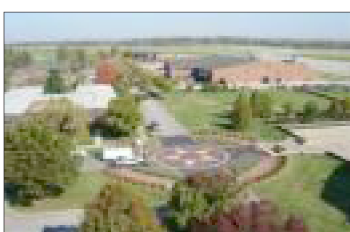
Consider the potential that within several decades a transformation plan asks that Scott AFB support other training – perhaps joint training with other services. The analyses here consider future requirements for training the following:

1. An aircraft similar to the Boeing 757 training at an altitude of 2000 meters
2. An aircraft similar to the C-130 training at an altitude of 2000 meters
3. Helicopter training with the Bell_J_2A at an altitude of 300 meters
4. Tracked vehicle training
5. Night training requiring dark nights

Our question, therefore is, "Where, in the vicinity of Scott AFB can these potential missions be after development with respect to the tested regional planning scenarios?"

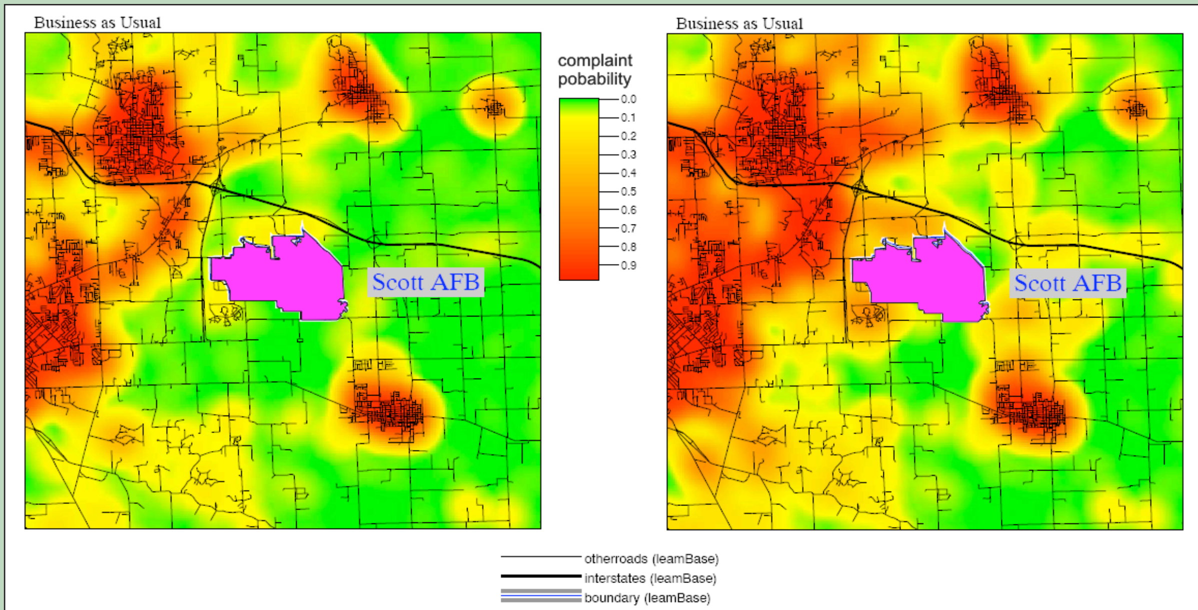
The first four questions address the tolerance of noise associated with the training by surrounding residential areas. For each analysis, each residential location is associated with concentric rings of complaint probability – training at more distant areas are associated with an increasingly lower probability of complaint. Each location on the map is then given a probability of complaint associated with every residential area across the entire map, and these values are combined to give an overall probability of complaint. In each of the maps, the training in the yellow areas is projected to generate less than a 5% probability of complaint, blue is about 60%, and red is above 90%.

Training with night vision goggles can be compromised with bright city lights associated with residential and commercial areas. The sky glow associated with bright lights, high humidity, and cloud decks can yield large areas unsuitable for night training. To generate artificial sky-glow maps, each residential and commercial location is allowed to brighten the sky at every other location in the area. Combining all of the sky-glow calculations at every location as a result of the surrounding urban areas yields a brightness index.

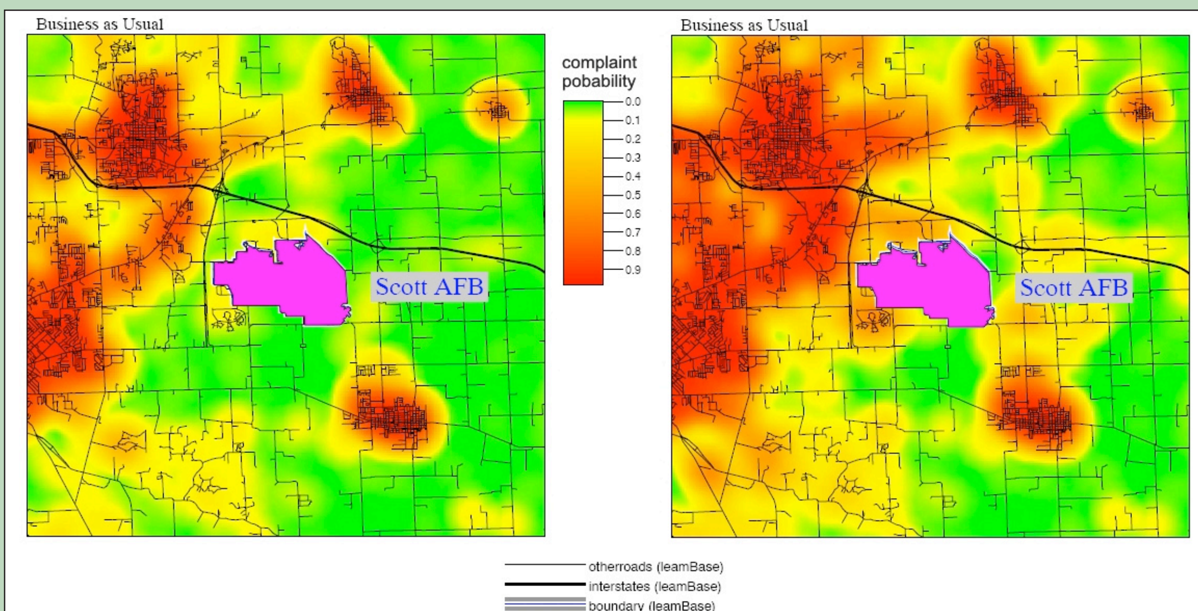


Below we consider first the training potential for the year 2000, followed by the training potential associated with each urban projection in the year 2030 in response to each regional planning proposal.

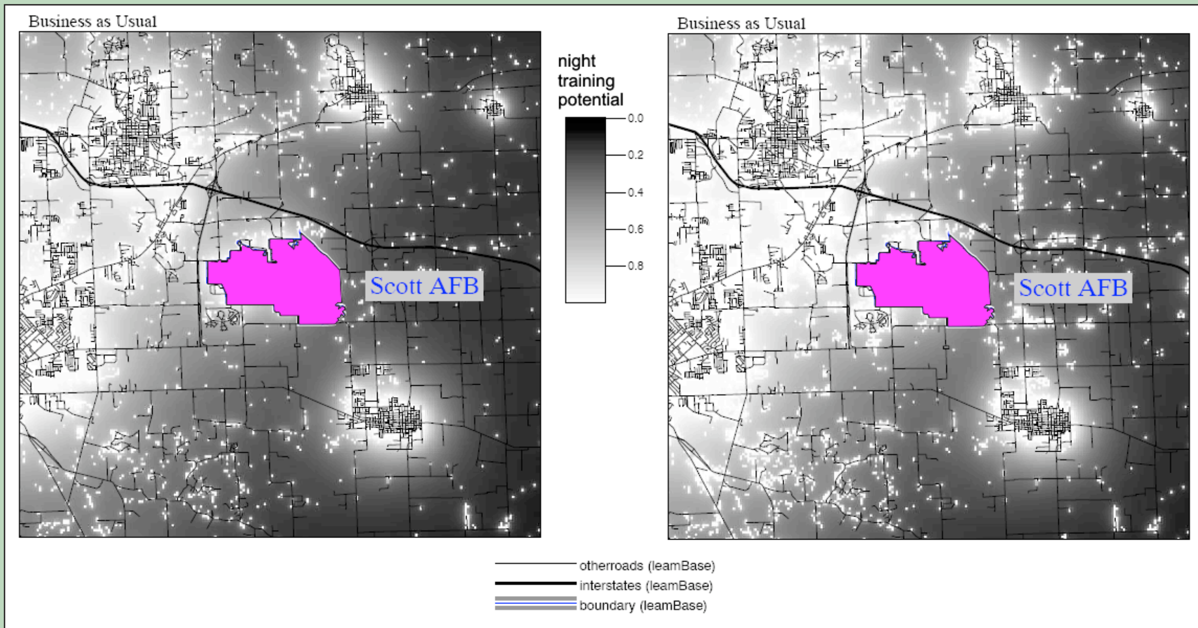
These maps show the complaint probability from surrounding residential areas BEFORE and AFTER growth in response to a BOEING 757 at an altitude of 2000 meters generating noise measured as: 72 dB @ 450 meters. Note the increased probability of complaints being generated by such an aircraft using Mid America Airport as urban growth continues into the future (map on the right) as represented by the increase of red areas to the west and north west of Scott AFB.



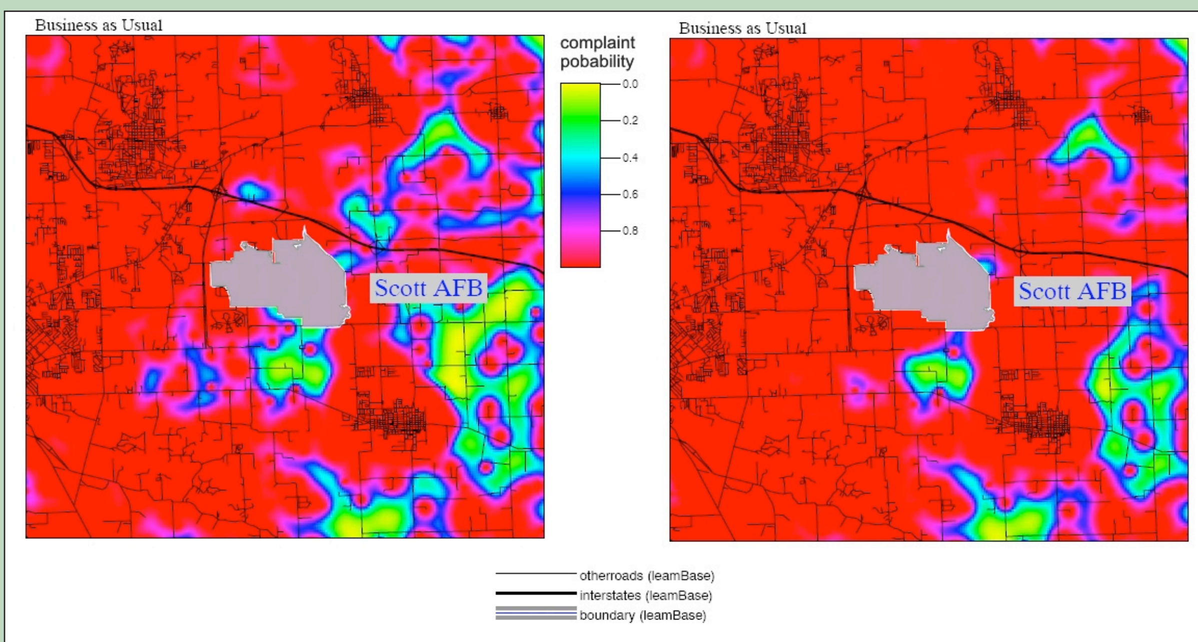
These maps shows the complaint probability from surrounding residential areas BEFORE and AFTER growth, in response to a C‑130 at an altitude of 2000 meters generating noise measured as: 99 dB @ 92 meters. Note the increased likelihood of complaints generated by this kind of aircraft training in the future map on the right.



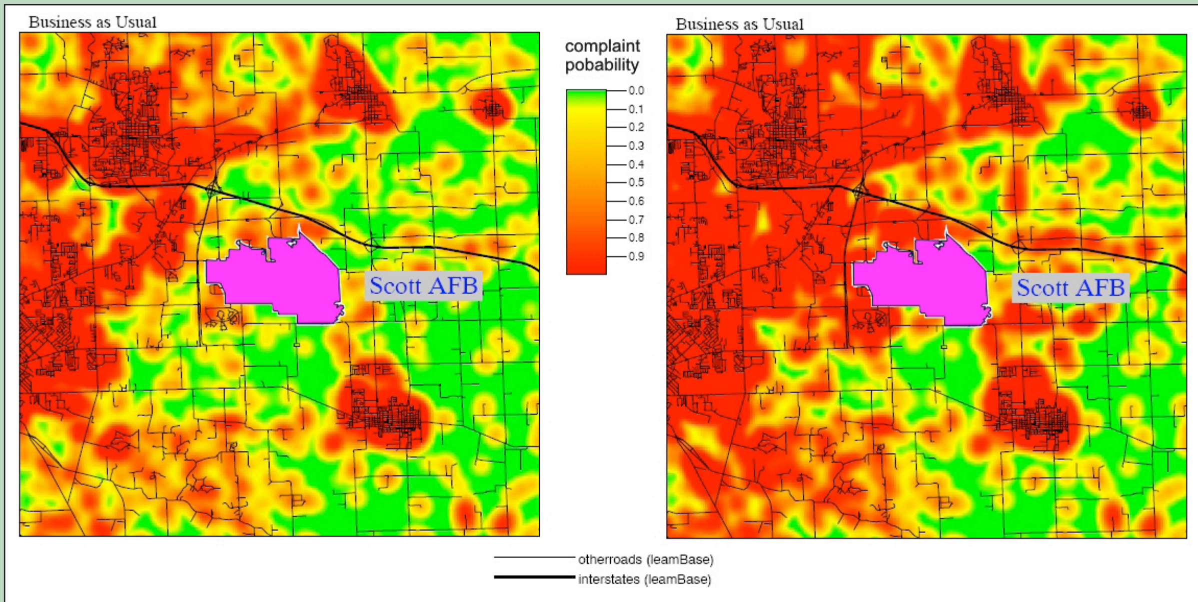
These maps show the relative potential for night training exercises BEFORE and AFTER growth in response residential lights reflecting off clouds along with high atmospheric humidity. Note the somewhat decreased areas of blackness in the map on the right (future training opportunities) vs. the map on the left (current training opportunities). It is within these areas of darkness that the military can effectively conduct night time training activities without interference from residential light pollution.



These maps show the complaint probability from surrounding residential areas BEFORE and AFTER growth in response to a tracked vehicle training exercise generating noise measured as: 60 dB @ 600 meters. Note the increased areas of high probability of complaint (red) to the west and south of Scott AFB.

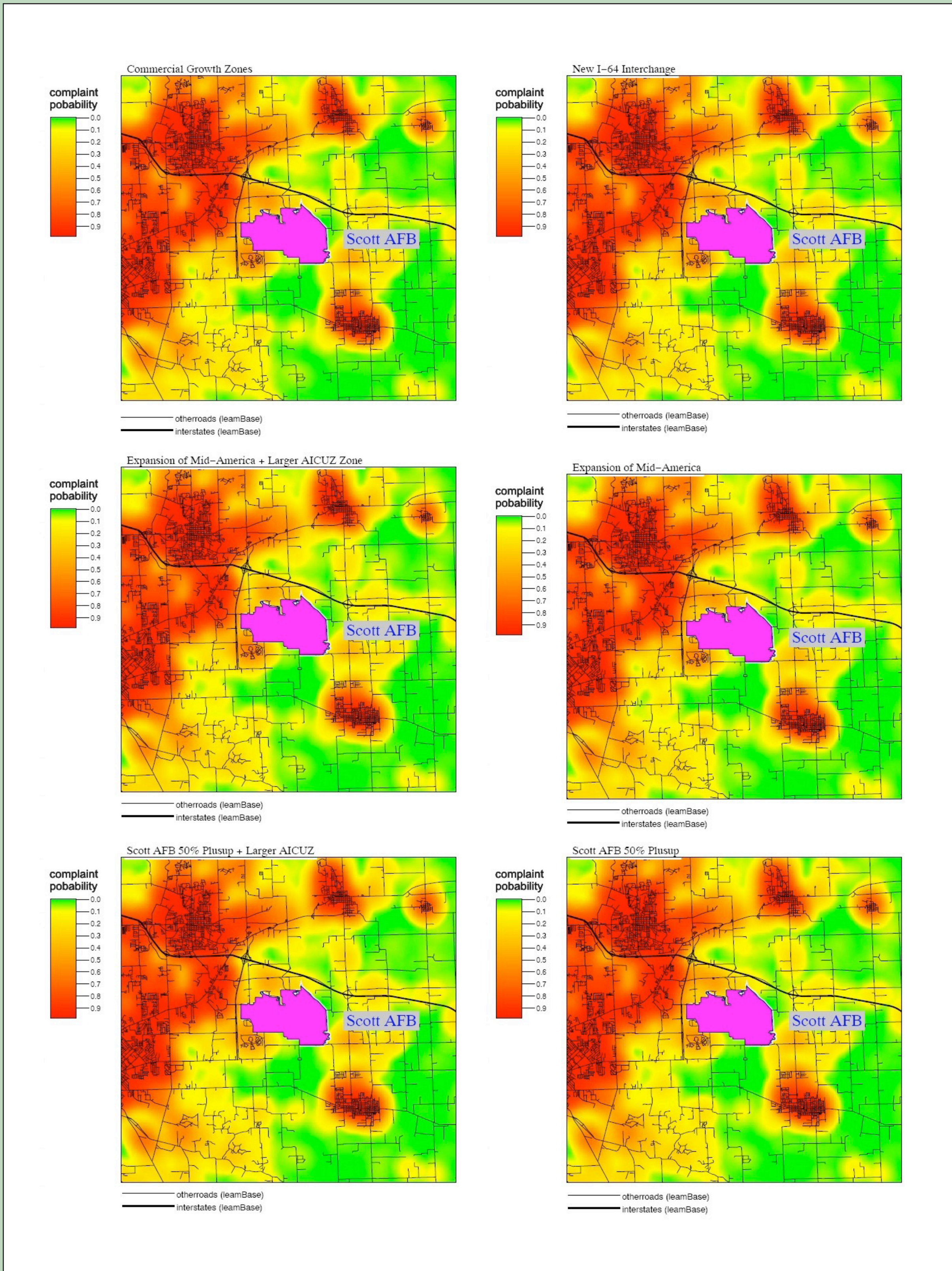


These maps shows the complaint probability from surrounding residential areas AFTER GROWTH in response to a Bell Jet Ranger helicopter at an altitude of 300 meters generating noise measured as: 100 dB @ 30 meters. Note the increase in probability of complaint to the south west and east of the Scott AFB.

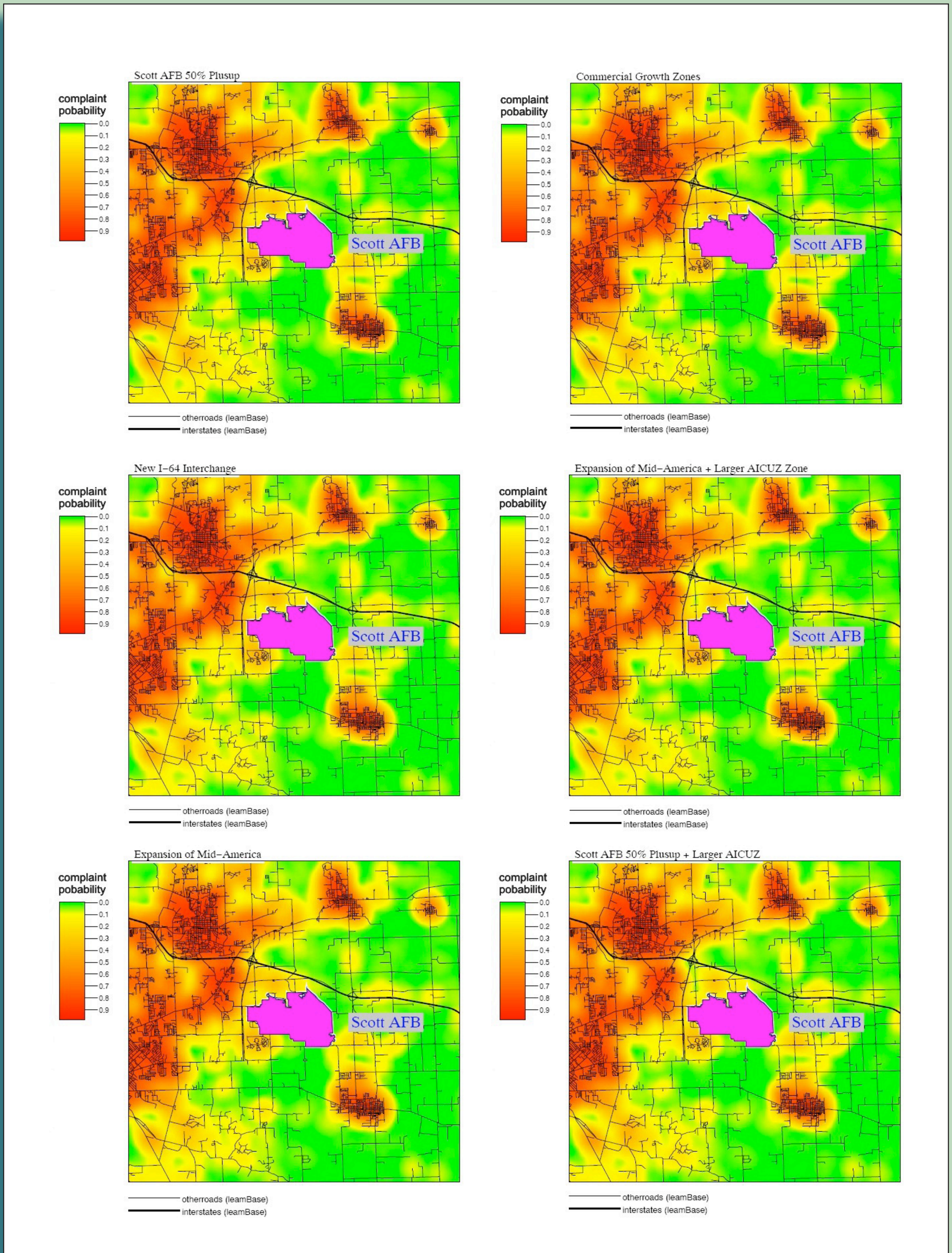


The following groups of maps examine the differences in probability of complaint between all the scenarios for each of the training exercises simulated in LEAMtom for the purposes of this report. The maps displayed below represent the last time step in each simulation, or what the region might look like in terms of complaint probability in the year 2030. Note that visually, all the maps for each training event seem identical at this resolution. Only on a fine-scale graphical analysis can the differences be detected between the images. The next section of this report summarizes a more in depth analysis of these training exercises for each of the simulations that were performed.

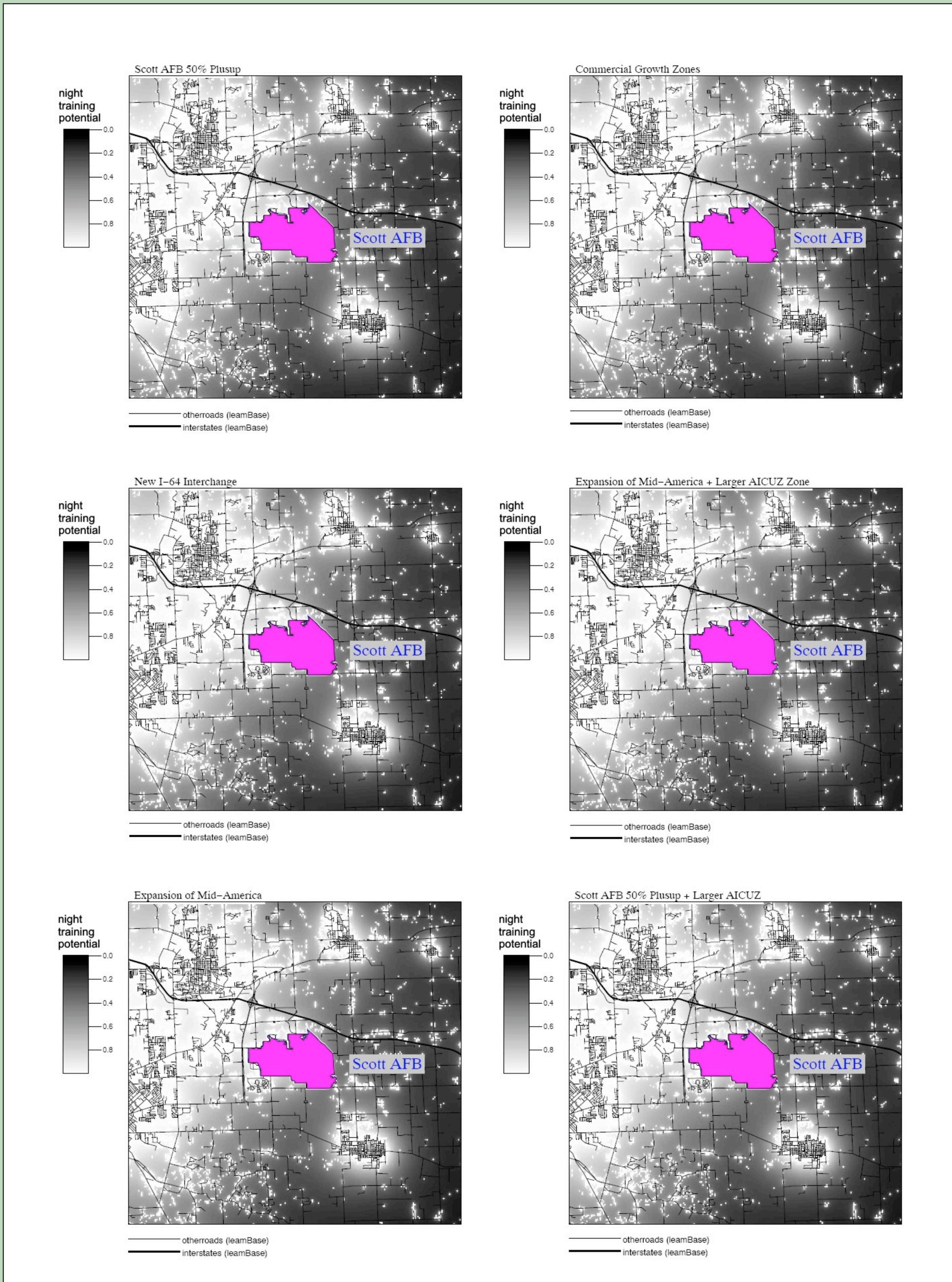
Bowing 757 noise complaint probability:



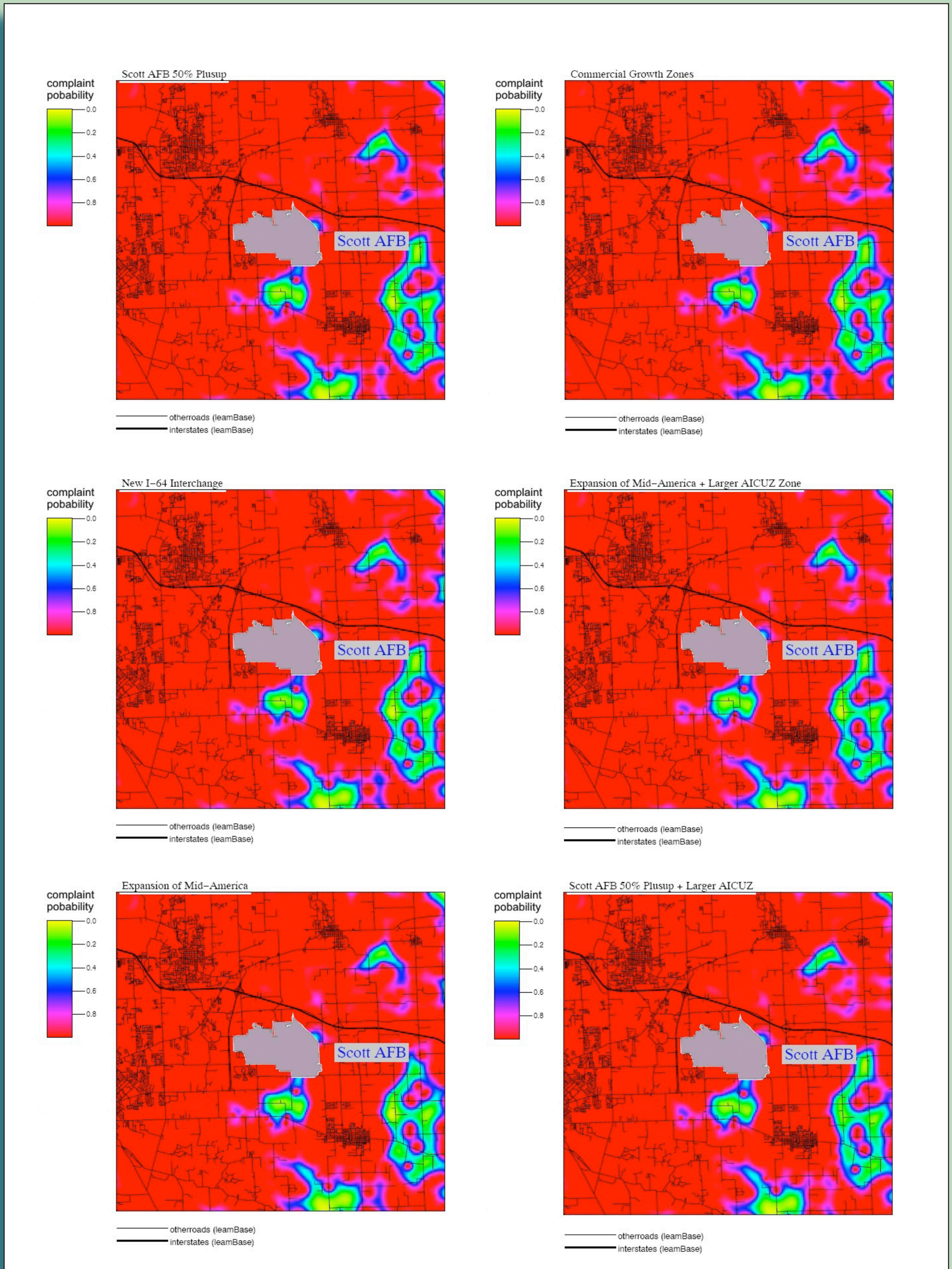
C-130 training complaint probability:



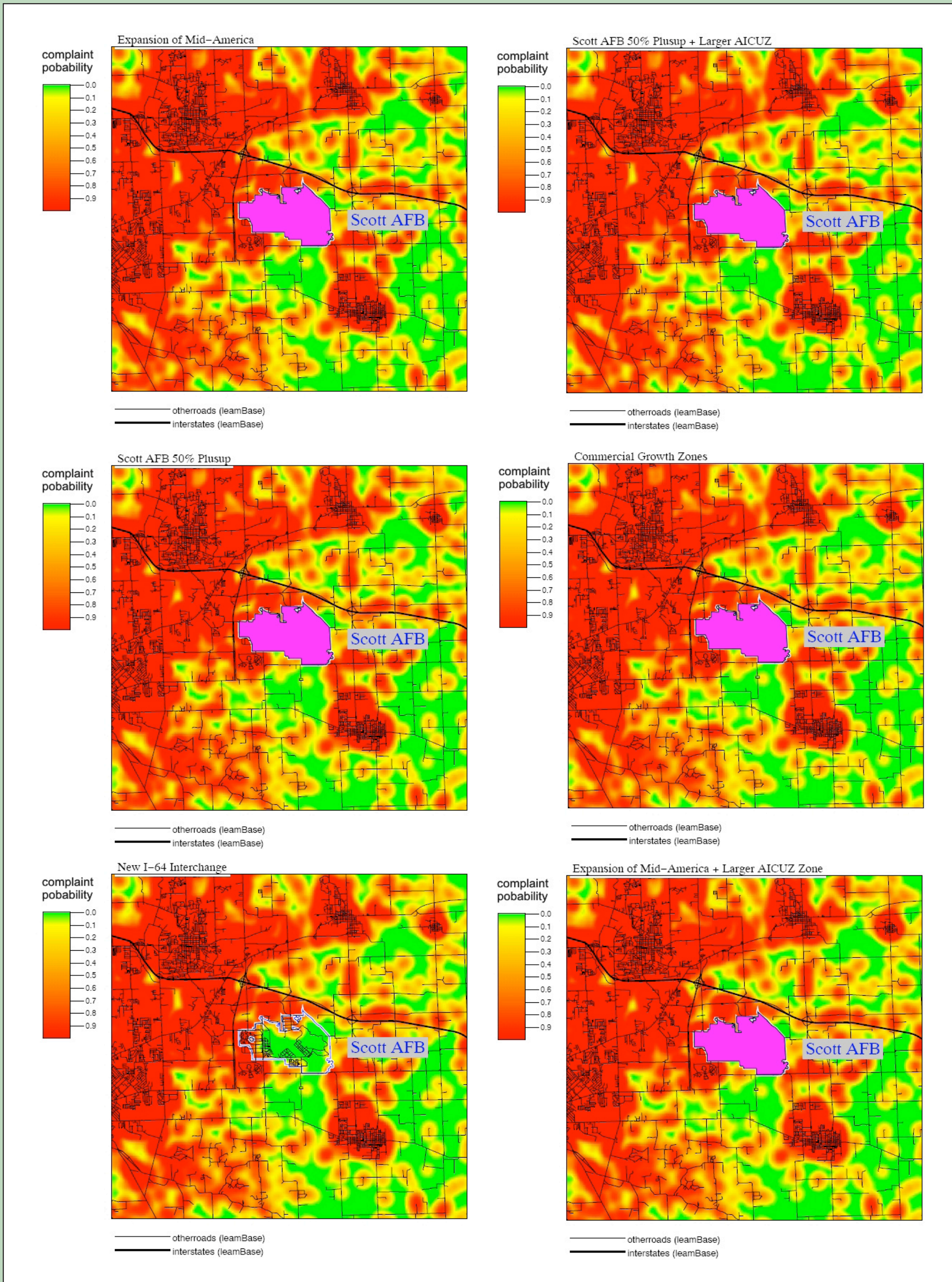
Night training potential:



Tracked vehicle training complaint probability:



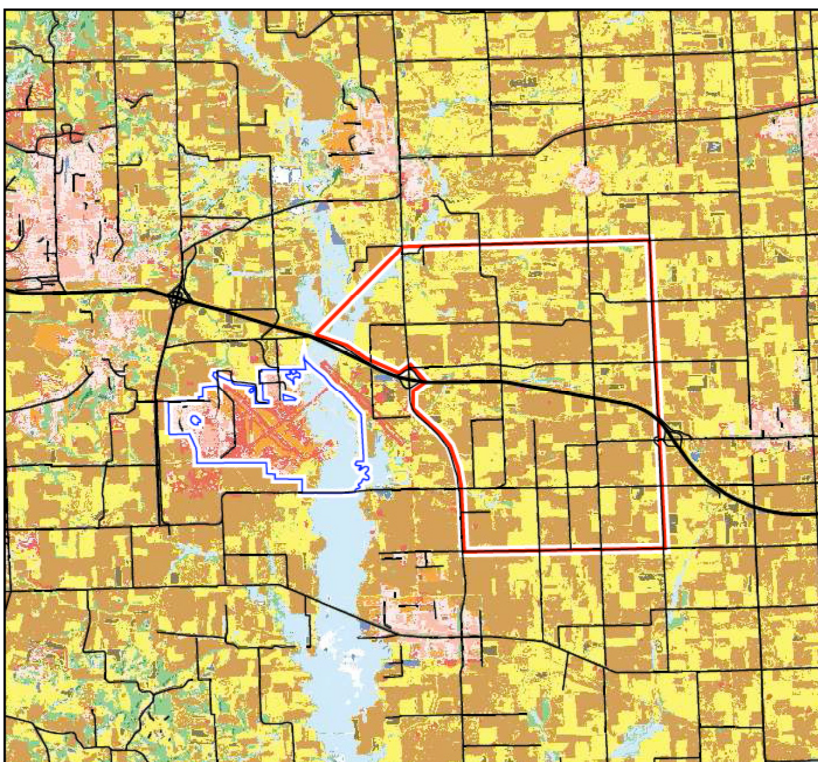
Tracked vehicle training complaint probability:



Summarizing the Scenarios

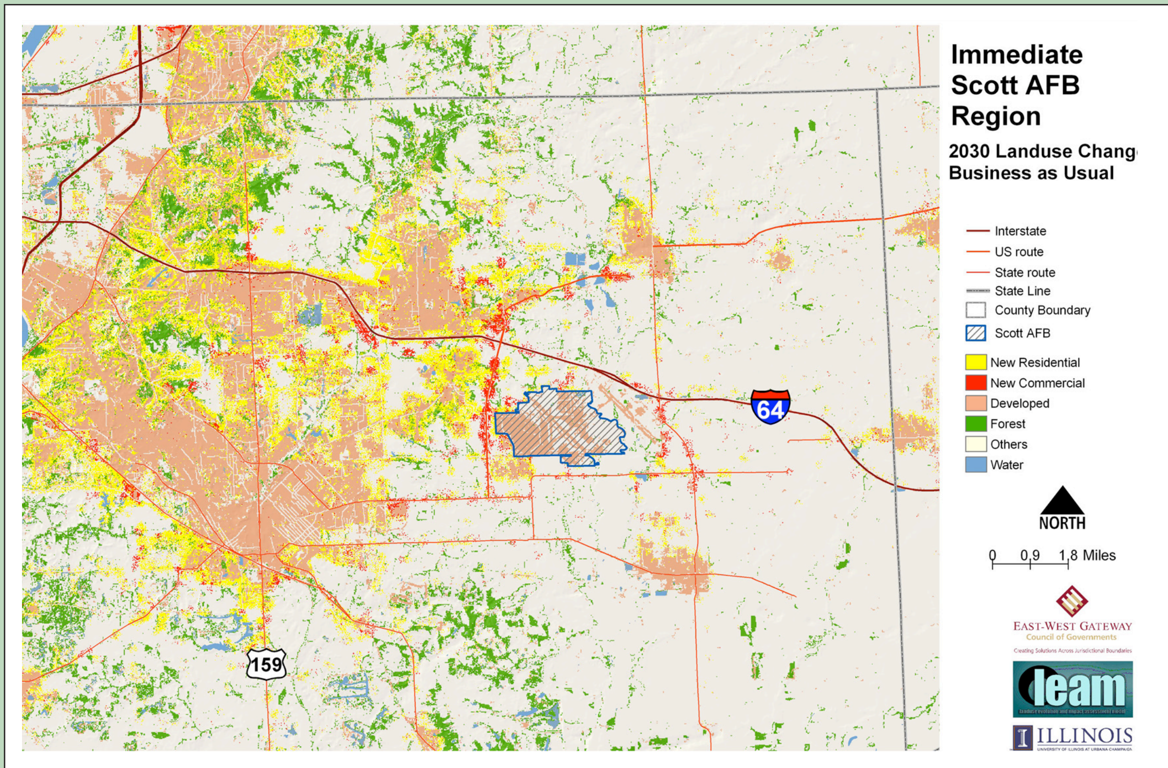
To summarize the result, consider the farmland area to the east of Scott AFB, outlined in the image with a red border. Mascoutah is to the southwest, New Baden to the east, and Lebanon and Summerfield to the north. Suppose that the Air Force might want to consider using some of this land to accommodate future air training missions, or a joint services command might want to conduct multi-service exercises in the area. The percent of area remaining in this polygon supporting each of the training types with respect to that originally available in 2000 was calculated. For the noise related training, a probability of complaint of less than or equal to 1% was considered. For the night training, a light index of .2 or less was considered suitable and the percent of that area is reported.

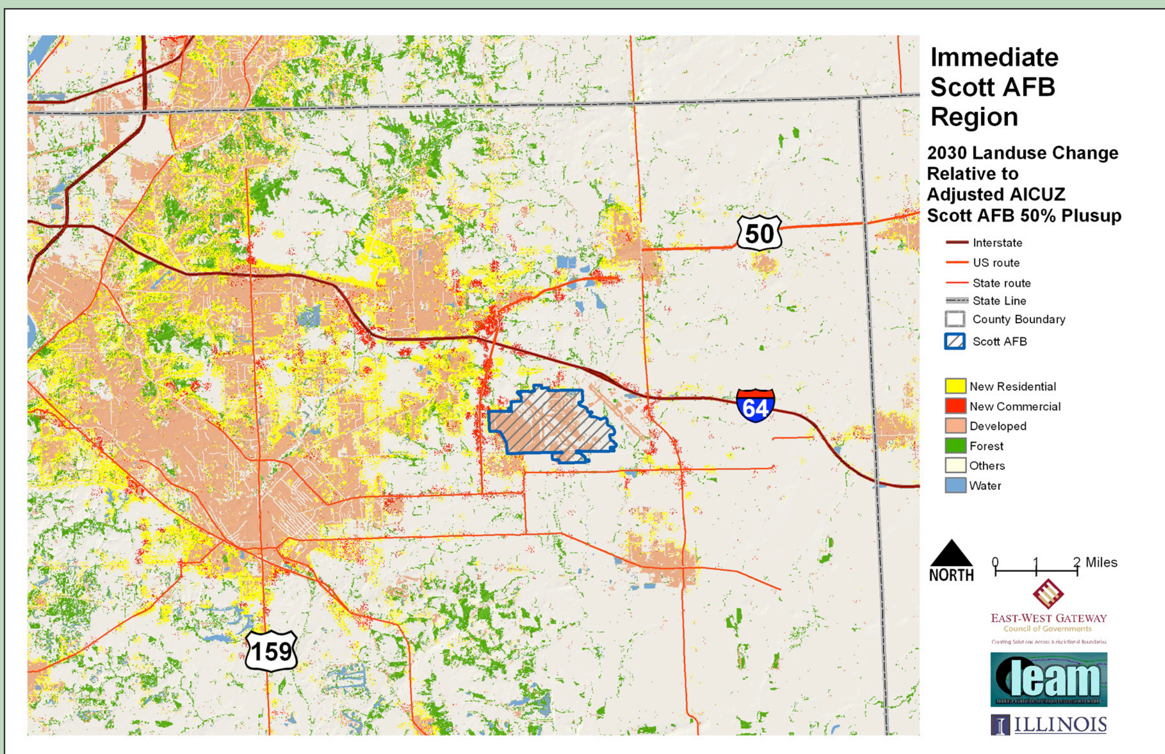
	Business as Usual	Commercial Growth Zones	New I-64 Interchange	Expansion of Mid-America + Larger AICUZ Zone	Expansion of Mid-America	Scott AFB 50% Plusup + Larger AICUZ	Scott AFB 50% Plusup
757 @ 2000m	71%	72%	71%	70%	70%	69%	72%
Bell J-2A @ 100m	58%	61%	60%	55%	56%	55%	59%
C130 @ 2000m	93%	91%	92%	91%	91%	88%	93%
Night Training – high humidity	58%	58%	57%	53%	52%	52%	56%
Night Training – low humidity	96%	96%	96%	96%	96%	95%	96%
Tracked Vehicle Training	0%	4%	6%	3%	0%	6%	7%



Potential Area of Interest for Future Expansion

Our selected area of interest for the purpose of this study covers about 20.25 square miles (12960 acres) and contained (according to the 2000 NLCD map) 56 acres of residential and 81 acres of commercial development. The simulated "Business as Usual" scenario generated an additional 160 residential and 76 commercial acres. This resulted in a total of 216 residential 157 commercial acres covering 1.7% and 1.2% of the area, respectively. Each of the other scenarios generated similar increases. Referring to the table above, these relatively small percentages have a significant impact on future training opportunities. For example, virtually no tracked vehicle training activities are possible and there is a serious decrease in night training and low-level helicopter training an a significant decrease in the aircraft training.


Immediate
Scott AFB
Region
2030 Landuse Chang
Business as Usual
Interstate
US route
State route
State Line
County Boundary
Scott AFB
New Residential
New Commercial
Developed
Forest
Others
Water
NORTH
0 0.9 1.8 Miles
64
159
EAST-WEST GATEWAY
Council of Governments
leam
ILLINOIS


Immediate
Scott AFB
Region
2030 Landuse Change
Relative to
Adjusted AICUZ
Scott AFB 50% Plusup
Interstate
US route
State route
State Line
County Boundary
Scott AFB
New Residential
New Commercial
Developed
Forest
Others
Water
NORTH
0 1 2 Miles
50
64
159
EAST-WEST GATEWAY
Council of Governments
leam
ILLINOIS